SPACE STATION PRELIMINARY DESIGN REVIEW

HEARING

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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SPACE STATION PRELIMINARY DESIGN REVIEW

THURSDAY, SEPTEMBER 27, 1990

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:41 a.m. in room 2325, Rayburn House Office Building, Hon. Bill Nelson [chairman of the subcommittee] presiding.

Mr. NELSON. Good morning. The committee will come to order.

Today we are going to review the status of a program that has been an important element of oversight for this subcommittee for the last five years. The Space Station Program, which this committee has strongly supported, is approaching a major—to use NASA language—a major milestone. It is the PDR program, Preliminary Design Review.

PDR is the point at which the Space Station Program finally has to confront and resolve the major technical and programmatic issues facing the program if the agency is to proceed further with the space station. As everyone knows, we are in an unusual confluence of events. There is a time of severe budgetary uncertainty, and we want to find out what options are being explored to deal with the potential drastic funding cuts that are potentially lurking out there.

Now, in this time of budgetary uncertainty, we are also dealing with another animal called sequestration. Cuts that are so large that they have been described as being like the atomic bomb, the effects of which would be so devastating its use is precluded. Yet we are still on the verge of budgetary brinkmanship facing the possibility of sequestration. That sequestration is closing in on us next Monday.

Let me just give you an example. I have a report from the appropriations committee here on the effects of sequestration. This is what it would do on the space program. The space station would be cancelled. The 10 planned shuttle flights during 1991 would be postponed or cancelled. The 11 missions for 1992 would also have to be postponed or cancelled, effectively suspending space shuttle operations until 1993. That's what we are facing.

It is a 32 percent cut in most domestic agencies, and it is a 35 percent cut in the Defense Department.

Today we are supposed to take up a bill called a continuing resolution that will, if enacted—and it is not at all sure we can get 219 votes to pass it—that if passed would have the effect come midnight on Sunday, to continue operating the Government at the

level appropriated basically for the present fiscal year, the one that ends two days from now.

Sequestration is another component of this whole thing. At any rate, in the allocation to the appropriations committees, we saw a level less than that requested by NASA be appropriated by the House appropriations committee. When the Senate appropriations committee allocated their various spending levels to their various committees, they even came in considerably lower, or it would, if we got that level of appropriation, it would require a $600 million cut in the amount requested by the President for the space station, if NASA chose to take that $600 million out of the space station.

We are dealing with considerably uncertain times. We often go through this kind of drill at this time of year. Then there is some little rabbit in a hat that is often pulled out, some little budgetary obfuscation that averts the disaster—some additional employment of budgetary blue smoke and mirrors. And yet we are rapidly running out of all those tricks of magic. We are down to the hard bottom line.

Who knows what it going to happen over the next several days? This does not have anything to do with the space program. What it deals with is a lot of budgetary politics. Indeed, it has to do with election year politics. It has to do with the changing nature of this democracy and single nature politics. It has to do with an increasingly polarized legislative institution.

All of this confluence of events is coming together at once. For an R&D agency such as NASA, we now find ourselves in an extremely uncertain time. We know back in the history of the Soviet program that there was considerably success because they had a constant level of funding, nothing dramatic in the increases, but a constant level they could rely on as they planned their program.

The peaks and valleys of the funding we have looped back in the past in NASA have been one of the causes of our wringing our hands. That's why this committee, in the last six years, has done everything it can to get a steady stream of funding, most of which we have been successful in obtaining. It has been a steady stream of funding on an upward incline. Yet we come to these times of great uncertainty, and now face the hard reality that because of budgetary and partisan politics, we are likely to see a cut in the space program.

If we are fortunate, the cut won't be a cut to this year's budget, but will be a cut to the President's request, and we will still have an increase. As you know, the President's request was quite generous. It was in excess of about 24 percent recommended increase. Of course, there is a lot to be done. That's why we wanted to have this hearing today, because you in NASA are getting ready for the PDR. We are facing considerable uncertainty in the budget.

Besides the budget, let's face the other challenges facing the station. We want to make sure NASA can deliver a station that meets this Nation's needs. So some of the issues we want to address are, can NASA assure this subcommittee that the technical problems can be resolved in the preliminary design review, or should we think in terms of fundamental redesign? That's question number one.

Question number two is, is the goal of a permanently manned presence in space still affordable and technically achievable?

Question number three is, are we putting an adequate amount of testing and verification in this program or is that being pushed off to a secondary priority?

Fourth, does the direction of this program match the budgetary and political climate and the commitments that will be made over the coming weeks?

I asked these hard questions because it is our responsibility as the space subcommittee to ask these hard questions. That does not diminish in any way our enthusiasm for this Nation's civilian space program, nor our support for it. It is the very cornerstone of our dreams as a people, this space program, and indeed the space station is a major component in our future dreams in space.

[The prepared statement of Mr. Nelson follows:]

OPENING STATEMENT
OF
THE HONORABLE BILL NELSON, CHAIRMAN
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

September 27, 1990

Today we are going to review the status of a program that has been an important oversight responsibility of this Subcommittee for the last five years. . The Space Station program, which this Subcommittee has strongly supported, is approaching a major milestone: the program-level Preliminary Design Review (or PDR).

PDR is the point at which the Space Station program has to finally confront and resolve the major technical and programmatic issues facing the program if the nation is to have the confidence to proceed further with the Space Station.

As everyone knows, NASA is preparing for PDR in a time of severe budgetary uncertainty. And we want to find out what options are being explored to deal with the potential drastic funding cuts on the horizon.

In addition, this nation is facing a rough sequestration. And everyone here needs to know that the impact of a lengthy sequestration will be the cancellation of the Space Station [HOLD UP CR REPORT]

Regardless of the budgetary situation, however, this Subcommittee needs to understand the other challenges facing the station. We need

to be sure that NASA is going to be able to deliver a Space Station that meets this nation's needs in space.

Issues we want to address today include questions of great importance to the future of the U.S. Space program:

- o Can NASA assure this Subcommittee that these technical problems can be resolved in the Preliminary Design Review or should we be thinking in terms of a fundamental redesign?

- o Is the goal of permanent manned presence still affordable and technically achievable?

- o Are we putting an adequate amount of testing and verification into this program, or is it being pushed off as a secondary priority?

- o Finally, does the direction of this program match the budgetary and political commitments that will be made over the coming weeks?

I want to make clear that we have supported and continue to support the Space Station program. It is the cornerstone of our future dreams in space.

We are honored to have Dr. William Lenoir, Associate Administrator of the Office of Space Flight; Mr. Richard Kohrs, Space Station Program

Director; and Dr. Jack Kerrebrock, Professor of Aeronautics and Astronautics at MIT and member of the NASA Space Station Advisory Committee join us today.

Now I would like to turn to Mr. Sensenbrenner for his opening statement.

Mr. NELSON. Dr. Lenoir, you have the support of this committee in that. But we must ask the tough questions. We are honored to have Dr. Lenoir and Mr. Kohrs here today, and Dr. Jack Kerrebrock, Professor of Aeronautics and Astronautics at MIT, and a member of the NASA Space Station Advisory Committee.

I am going to have you offer your testimony. I will ask Dr. Kerrebrock to come and offer his testimony, and then the members can get to the questioning of all of you. We are not going to have any time limits. We are going to get this into a free-wheeling discussion with plenty of follow-up, where we can get our questions answered.

I would like, Dr. Lenoir, if you don't mind, instead of reading your statement, if you would give us a summary. Dr. Kerrebrock, if you would likewise give us a summary. Your statements have been made available to the members. Then we will get right on in to the questioning.

Dr. Lenoir?

STATEMENT OF DR. WILLIAM B. LENOIR, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C.

Dr. LENOIR. Thank you, Mr. Chairman. I would like to submit our statement for the record.

I would also like to thank you for your kind words and to point out that as we sat down here, always having in mind the financial budget issues you mentioned in fiscal year 1991, we appreciate your reminder to us as to how things may be going with our notepads here on the Select Committee on Hunger that we find here. I hope it is not too big a harbinger as to where fiscal year 1991 may be taking us.

The Space Station has had a good year. It is somewhat frustrating to us that you find it difficult to gather that from the public press, but if you recall what Mr. Kohrs and I said a year ago, that the Space Station was going to accomplish in the year that is now behind us for the monies we did get in fiscal year 1990, I cannot think of one thing we said we would do that we have not done.

We have made one year of progress. The program is one year closer to the first assembly flight than it was a year ago. This is the first time the program has been able to say that, that in real time we are approaching the launch. We also have the same two people sitting at the table that we had here a year ago. That is probably also a first.

Mr. NELSON. That's a very significant accomplishment.

Dr. LENOIR. It has been a trying summer, and there were days when I wondered.

We said that we were going to transition, in this what we called the Preliminary Design Review, from a paper product to a hardware product. We have done that. At the Marshall Space Flight Center we have had an extensive set of experiments done on engineering test hardware to select the technologies in the environmental control system, in the water recycling loop and in the oxygen recycling loop. We have had, if you like, a competition between competing technologies and we have winners. We have selected

them and will be building, in the coming year, additional hardware for integrated tests in a simulated module.

The power system has working engineering hardware in the laboratory and portable tank cells we have operated in the vacuum chamber in order to look at the interaction with space plasma. We have built up extravehicular activity hardware in order to assess some of the questions that have come out of the concerns this year. We indeed are a program that now has hardware as its product, not paper.

We said this was the year of preliminary design reviews. We showed a schedule of when those subsystem and element PDRs would happen, and they did happen, on that schedule. We have filled them. We are poised to complete. We have the total integrated program Preliminary Design Review, everything taken together and how they play against each other, yet to complete. That is scheduled for completion in December, as it was a year ago. We have made excellent progress there.

We indicated that we wanted to find the issues and work on the issues and resolve the issues, as part of our Preliminary Design Review process. We have done that. Mr. Kohrs and I set up a team. It was called the "Fisher-Price study" in the newspapers, the Extravehicular Maintenance Task Force, also known as Fisher-Price, since the chairmen happened to have those names. We set them up. That was not an outside organization. They reported to us.

Frankly, we found that we had more requirements for EVA than we thought, and we thought there were going to be a lot. We have vigorously worked that off in the ensuing six months. Their initial estimate, if we did nothing and proceeded down the path to do all our repairs with EVA, their initial estimate was that it could require as many as five EVAs per week.

By the time they submitted their final report in the summer time frame, with recommendations for how to work that down, most of which we have subsequently accepted into the program at a surprisingly modest cost, we are now looking at requiring one EVA every eight to ten days on the basis of their final report. As Mr. Kohrs may allude to, in some of our solutions to other problems, we have actually simplified that and made that a little less.

Our goal, as I said a year ago, was to be at one a month. Our requirement is to be at no more than one a week, and we are right in the middle of those numbers where we wanted to be. On power, we have committed to provide 30 kilowatts of power to the user community. We recommit to that. We intend to meet that commitment.

In June, when we looked at that in our systems engineering effort, we concluded that our housekeeping of the Space Station to operate it as a facility was going to require not 45 kilowatts, as we had allocated, but 60 kilowatts, way over budget. In the two months that have ensued, we have worked vigorously to work that down. Our latest estimate last week is 47 kilowatts. We have two more kilowatts to go, and frankly most of that is on the international side of the ledger; on the domestic side we are within our allocation.

On weight, we wanted to be no more than 512,000 pounds for the first phase configuration. In June when we did our systems engi-

neering study and summed up what it looked like from the currently existing preliminary designs, we estimated 656,000 pounds, considerably overweight. Much as we have done with the power and the EVA, we have worked vigorously on that, changing materials, changing requirements, simplifying our concept. That is now down to 528,000 pounds, less than half of a shuttle flight's overage at this point, and we are not through. We are continuing to work that down.

As the year has gone on, our relationship with our international partners has continued to get better and better, as exemplified by our agreement to go to a standard rack design. We had difficulties with the European partners, Japanese partners and United States partners, each insisting we wanted our rack design because it was easiest for us to get to. We have all compromised—we have given a little and taken a little. We now have one rack design so that users of the Space station facility can build to one interface and it does not matter whether it is operated in the European module, the Japanese module or the United States module.

We are well poised after this very successful year for fiscal year 1991. We will complete the integrated PDRs, we will begin our detail design, we will begin development of engineering hardware and the testing of that hardware. We will continue development of our ground facilities, and actually begin the construction of the flight, photovoltaic arrays, the solar cells.

But I am sorry to report that because of the funding situation, the outlook is not as rosy as it could have been. We said our number one problem was funding adequacy and stability. We are at the point now where we don't know about the adequacy, because it is still possible for us to get the fully requested budget for fiscal year 1991.

But the stability issue has already hit us. We have had to get off of our plan in the tail end of fiscal year 1990 that was building toward the anticipated fiscal year 1991 budget, and we have lost some momentum, because we could not afford to grow more and then be faced with sequestered or severely cut budget, and even bigger layoffs. So we have had to suspend our growth, freeze our configuration in a people sense, and that will cost us some time. There is no question about that. We have lost some number of months.

We are very optimistic. We don't believe a redesign is necessary unless the funding won't support what we have. We have well-documented requirements. We have documented very well how we meet those requirements. We see no technical or management constraint to affirmatively putting man in space. That's very much our next objective.

One of our key objectives for the coming year is the verification program you mentioned earlier. We must define in greater detail our verification plan, so that hardware that goes up on the first flight can be integrated with hardware that goes up on the 15th flight, even though it did not exist when the first set was launched. That has been in our plan, and continues to be in our plan, to bring our verification plan up to the final configuration as we come out of the Preliminary Design Review.

Do the dollars match our plan? That's the $64,000 question. Initial hints are that they might not. If they do not, we will have to take schedule and/or content more out of the program. With that, I would like to ask Mr. Kohrs to say a few words, and we are happy to answer questions.

[The prepared statement of Dr. Lenoir follows:]

Statement of
William B. Lenoir
Associate Administrator
for
Space Flight

National Aeronautics and Space Administration
before the
Subcommittee on Space Science and Applications
Committee on Science, Space and Technology
United State House of Representative

Mr. Chairman and Distinguished Members of the Subcommittee:

I am pleased to be here today to discuss the status of the Space Station Freedom Program. Over the past year, we have made substantial progress toward our first assembly flight in March 1995. Our momentum has been strong, but recent events in the FY 1991 budget process have forced us to slow down. At this time last year, FY 1990 budget adjustments caused us to thoroughly reassess the content and schedule of the program. Program options were assessed with the active, and sometimes stressful, participation of the entire Space Station Freedom community - the users, our international partners, the program contractors, and our civil service work force. As you know, we successfully realigned the content and schedule of the Space Station program with the reduced FY 1990 funding level, and have fully implemented the necessary adjustments. We are pleased that the program passed through this difficult period without an attendant increase in total development cost. This year, the Space Station program has remained on budget and on the revised schedule, although I am gravely concerned about the threat of another destabilizing shortfall in our FY 1991 appropriation.

As a result of our continued progress, today we are one year closer to our first launch than we were last year. Many preliminary designs are complete, with the remainder on schedule for completion shortly. Progress has been excellent on this front. With these preliminary designs complete, we are in the process of reviewing each system and subsystem design to ensure compatibility with the program requirements. We will review and approve the integrated program preliminary design in December of this year.

Following this review, engineers at each Work Package will continue detailed design based on the approved preliminary design. These final, detailed designs will lead to manufacture of the various flight hardware elements of the Space Station. Thus, completing the preliminary designs is a crucial and significant milestone in the Space Station program.

2.

We have completed preliminary designs and subsequent review for most of our elements and systems. The results of these reviews have been as expected; many minor issues to work, a few more significant issues. There have been no "show-stoppers" identified, and we believe we can remain within the budget profile characterized in our FY 90 budget plan.

At Work Package 1, subcontractor design reviews as well as system and element reviews were completed during this past year. The system designs for the environmental control, thermal control, internal audio and video, structure, software, electrical power, data management, fluid management, and manned systems were all confirmed at the contractor and work package level. In addition, the lab element review was also completed and the lab design was endorsed. In the environmental control area, comparative (competition) tests were conducted on engineering hardware for each of the subsystems by the prime contractor, and design selection was made, based on performance, of the following: Static Feed water Electrolyzer System for oxygen generation; Four Bed Molecular Sieve for carbon dioxide removal; Sabatier process for carbon dioxide reduction to oxygen and methane; Multifiltration processes for potable and hygiene water preparation; Vapor Compression Distillation for urine recycling.

At Work Package 2, subcontractor design reviews as well as element and distributed system integrated project reviews were completed during this past year. The distributed Thermal Control System, the Communication and Tracking, the Guidance, Navigation and Control, the Data Management System and the Extra Vehicular Activity System preliminary designs were confirmed at the contractor and work package level. The element level preliminary design for the airlock, node, truss assembly and the Crew Health Care System were also confirmed throughout all of these reviews. No major design changes are required, minimal cost impact is anticipated, and endorsement was achieved from other Work Packages, the international partners, and the Program Office.

Work Package 4, following 50 lower level design reviews, held three major design reviews: Photovoltaic Power Module, Power Management and Distribution System (including software) and an overall end-to-end power system review. The Photovoltaic Power Module review confirmed the power generation and storage design using silicon solar cell arrays and nickel hydrogen battery cells, with a redundant single-phase ammonia thermal coolant loop. The Power Management and Distribution design review confirmed the design approach for the 160 volt Direct Current (DC) primary distribution, with 120 volt DC secondary distribution and the overall design approach, including fault detection and isolation. The end-to-end power system design review confirmed the overall performance of the electrical

power system and its planned approach for maintainability, reliability, safety and prelaunch/launch/on-orbit operations. No issues were identified that resulted in any major design changes, increases ~~in cost,~~ or delays to the schedule. The Work Package review board and program senior management agreed that the power system was ready to move into the detailed design phase.

Going into the preliminary design review process, we sought out particular areas where we suspected work package-to-program and work package-to-work package interfaces were most likely to be out of synch. This process enabled early identification and evaluation of several potential problem areas with ample time to refocus efforts and resolve issues. The External Maintenance Task Team (EMTT, also known as the Fisher-Price team), which evaluated EVA requirements, and the "Turbo Team" that is evaluating weight and power resource allocations and requirements are results of this early focus on potential problem areas. In both of the above cases, this process led to identification of solutions and relatively minor modifications to the baseline plan.

More specifically, the EMTT final report and an independent, companion External Maintenance Solutions Team report found that, with implementation of several recommendations, EVA time could be reduced to an EVA every 8 to 10 days during the mature operations phase of the program. This number contrasts with raw estimates as high as 5 EVA's per week just six months earlier. We have been encouraged by this progress and expect that we will bring the assembly phase external maintenance requirements to equally manageable levels by applying the same approach. We will continue to work on reducing EVA requirements as a major priority, and anticipate having a strategy for solution to the assembly phase problem by early October and implementation of the solutions for both phases fully in place by the end of the calendar year.

Progress has also been significant in reducing weight and housekeeping requirements. After nearly two months of intensive evaluation, we are very near our baseline allocations for both weight and power. We have made substantial progress in Space Station weight, reducing it from a high estimate of 655,700 lbs. in May to 527,960 lbs. today. This is within 3% of our baseline allocation of 512,200 lbs. Some specific examples of weight saving changes include: simplification of the Thermal Control System configuration (9,828 lbs.), 1/3 battery reduction (6400 lbs.), integration of O2/N2 supply and storage pallets (5250 lbs.), weight-optimized power distribution (4556 lbs.), adjusted DC to DC converter architecture to include 6.25 kW devices (3700 lbs.), scrub of the propulsion module attach structure (3012 lbs.), and numerous others. This process has not only reduced our

estimates of final weight by over 127,700 lbs., but has also significantly improved our confidence in the validity of our weight estimates.

In a similar manner, housekeeping power requirements have dropped from a high estimate of 59.9 kW in May to 47.4 kW today, also very near our baseline allocation of 45 kW. Some of these savings have come from: lab equipment duty cycle modifications (4720 W), Data Management System architecture scrub (2378 W), and manned system power reductions (1445 W). The vigor with which we attacked the power reduction problem demonstrates our commitment to provide at least 30 kW of average electrical power to the users. We reaffirm that commitment. Progress in both of these areas demonstrates the ability and effectiveness of our management team to deal with difficulties in the program. Both the user community and our international partners have been heavily involved in these resource scrubs.

A significant amount of engineering test hardware has been fabricated and actual engineering tests have been performed as part of the preliminary design process. As mentioned earlier, Work Package 1 completed several key Environmental Control and Life Support System tests : the four-bed molecular sieve which removes CO2 and moisture from the cabin atmosphere, the oxygen recovery system which reduces CO2 and converts water to oxygen, the liquid waste recycling system, the vapor compression distillation system which recovers and recycles water, temperature and humidity control flow, and the core module simulator which simulates the overall configuration of all the module and life support systems. Work Package 1 also conducted airflow/fire suppression tests for the U.S. lab, proof pressure tests and leak rate tests of the prototype lab module, debris protection testing (837 tests so far), and a modal vibration survey.

Work Package 2 delivered Crew and Equipment Transfer Aid hardware for launch and testing on STS-37, completed preliminary debris impact testing and completed initial ground system review with the Canadian Space Agency. It has also performed extensive testing of robotics and human interaction in Orbital Replacement Unit changeout exercises. A model of the mobile transporter has been constructed and is being used to test the translation sequence, the rotation sequence, and the plane change sequence, which will be required in orbit to move the mobile servicer around the Station truss assembly. Additionally, numerous tests have been performed in neutral buoyancy verifying EVA tasks, such as external maintenance.

Work Package 3 is completing critical design for the first test flight of the Flight Telerobotic Servicer (FTS) system: the sensors, hand controllers, data management and instrumentation,

manipulator, and force torque sensors. In order to accommodate all aspects of this planned test flight on the Shuttle, it has been necessary to delay it to November 1992 from its original assessment of December 1991. The flight unit remains on schedule for its launch in March 1995. The FTS contractor also has in place an aggressive program for the specific purpose of evaluating and transferring applicable technology from the FTS program to U.S. industry. This technology has potential to provide a boost to the domestic robotics industry and the manufacturing sectors.

Work Package 4 completed testing of DC to DC converter bread boards, and has built a full scale mock-up of a photovoltaic panel and beta gimbal. The mock-up will be used in neutral buoyancy testing to collect early information on the stowed configuration, assembly, and maintenance performance of the photovoltaic arrays.

Internationally, an agreement was reached with the partners on an international standard payload rack for use throughout the Station (i.e., on the U.S. Lab, the ESA Lab, the JEM Lab, and the other elements). This agreement is highly significant in that it simplifies the outfitting process, provides the flexibility for placing experiments in any of the modules and provides the user with a set of standard interfaces to which to design.

After adjusting their programs to the budget-driven changes in the U.S., the international partners are also proceeding with their preliminary design activities. The Canadian program has completed its preliminary design, Japan is working toward the review of Japanese Experiment Module (JEM) preliminary design in October of 1991, and the Europeans will complete their flight element preliminary designs in mid 1992. All of the partners are coordinating their efforts through a continuing series of joint technical reviews which provide early opportunity to identify and resolve program or system issues. Strong political and financial commitments have been made by all the international partners. Space Station is a key element of the western world's space program and future space plans. As this Subcommittee is well aware, the budget reductions we have experienced over the last few years have shaken the partners' confidence in the U.S. as a partner in large scale science and technology cooperative ventures; the potential FY 1991 budget reductions threaten to make matters worse.

NASA has requested $2.45 billion for the Space Station in FY 1991. This amount is needed to implement our planned efforts and to meet the objectives of the Space Station Program. Our activities planned for FY 1991 are critical to the success of the program, and should not be disrupted. Along with the scheduled completion of the integrated system Preliminary

Design Review, Fiscal Year 1991 plans include: beginning the detailed design phase; development hardware fabrication and testing activities to support the critical design review; and construction of key ground facilities required for testing, training, integration and control such as the Space Station Processing Facility and the Neutral Buoyancy Laboratory. We also plan to begin early production of solar cells and blankets. We need to receive our full request in FY 1991 for funding these ground facilities which are imperative to support the first assembly flight in March 1995.

The threat of significant FY 1991 appropriation shortfall, compounded by the threat of an initial sequestration, has already forced us to lose critical program momentum. At a minimum, time has already been lost. Cuts to our FY 1991 budget request will force further delays and more capability deferrals and deletions, and will once again cause our partners to seriously question the viability of their programs vis-a-vis our own. Without a strong, stable funding commitment, the Space Station development effort will again suffer further disruptions and delays as we have to redesign and rephase. Every time the program is disrupted by a budget reduction, thousands of man-months of effort must be diverted from design and development to program replanning activities. Clearly, this environment is not the way to allocate scarce financial resources efficiently.

As we stated one year ago, funding inadequacy and instability remain the top two threats to the Space Station Freedom program. Mr. Chairman, we ask for the Subcommittee's continued support for this funding.

STATEMENT OF RICHARD H. KOHRS, DIRECTOR, SPACE STATION FREEDOM PROGRAM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C.

Mr. KOHRS. I would just like to elaborate a little on the PDR that Bill talked about. This year we have done up to 80 PDRs at various levels. Level 4, which is the prime contractors full work packages, then Level 3 which is the work package managers at the four centers, have built up this tree. We culminate this in an integrated systems PDR which is scheduled for November and December with a full board meeting and full approval coming out just before the Christmas holiday.

The projects are moving down the path based on their PDRs and we have not stopped working. We are working on critical designs. If you look at our detailed schedules, you will see that we have actually conducted, for some small components, critical design reviews on things like a photovoltaic cell that makes up the photovoltaic array.

The program is moving and it is success oriented. If we see something that makes us have to stop it, we will stop it and go back. But the key thing that Bill mentioned is that to keep this momentum going, we have to get through our integrated PDR in October and November, and to really make progress next year.

My plan is--and it is a little bit subject to how the budget plan comes out—but my plan today is to forge ahead and get this integrated PDR completed, get our new baseline established, and move forward.

I want to mention some products that will come out of the PDR. There will be a new assembly sequence. We will have integrated all the inputs to come out and say it may take half a flight more or half a flight less, or we may have to rejuggle how we reassemble the vehicle. But that's normal business.

We will come up with a new way to power allocations based on our weight and power scrubs we have been doing. We will come up with EVA task baselines. We will come up with tele- operated robotic task baselines. And, as Bill mentioned last, we will come up with a systems verification baseline as to how we are going to satisfy standing up later and saying that the vehicle can be integrated on the ground, and say it is safe to fly and to be put together.

Over the last year, we have put the organization in place. We have a strong Level 2 office that we have strengthened this last year in Reston. We have strengthened the projects, and the contractors have strengthened. The only thing I think is key is the money stability, so we can keep on track.

Dr. LENOIR. Mr. Chairman, we very much appreciate the support we have gotten over the long haul from this committee. This year more than most, we need your support and your help.

Mr. NELSON. We have a vote in progress, so the committee will recess and come right back. The committee will stand in recess.

[Recess.]

Mr. NELSON. The meeting will come to order.

Jack Kerrebrock, Professor of Aeronautics and Astronautics at MIT, was Associate Administrator for Aeronautics and Space Technology in NASA from 1981 to 1983. He is a member of the National

Academy of Engineering, and was a member of the National Commission on Space. He is currently heading the EVA and Robotics Subcommittee of the Space Station Advisory Committee.

Dr. Kerrebrock, we are pleased to have you here.

STATEMENT OF DR. JACK KERREBROCK, PROFESSOR OF AERONAUTICS AND ASTRONAUTICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASSACHUSETTS

Dr. KERREBROCK. Thank you, Mr. Chairman.

I appreciate the opportunity to discuss with you the matters of Extra Vehicular Activity Robotics and the capabilities they offer for the assembly and maintenance of the Space Station.

The Advisory Committee's activity in this area was initiated by a discussion with Dr. Lenoir some year or a year and a half ago, in which he expressed a desire for the committee to address a number of questions concerning EVA external maneuvering units, which is the technical term for space suits and life support systems, and also tele-operated and robotic space operations.

The Advisory Committee judged these to be a set of interrelated activities and established this subcommittee, which I chair, to inform itself about these matters and carry that information to the parent committee. We have been working on that for about a year now. We have briefed the committee and offered a set of findings and some thoughts to NASA management. I intend to summarize those here. I have submitted a prepared testimony, and I will make the oral presentation somewhat briefer than that.

The findings really fall into four categories concerning first the context of planning for Space Station Freedom's assembly and maintenance, the findings of the external maintenance team, or Fisher-Price team, the status of planning for external maneuvering units, or space suits, and finally the status and planning for use of tele-operators. I would like to present some conclusions after I have discussed these matters and recommendations being offered to the Space Station management.

First, on the matter of the context, the planning for the assembly and maintenance of Space Station Freedom has been taking place in a complex and difficult environment. The station is in preliminary design, as you observed this morning, with a system PDR to take place in the fall of 1990, hopefully by December. So planning for the assembly must necessarily be tentative. It cannot be finalized until the actual design of the space station components is known.

On the other hand, the assembly and on-orbit maintenance are such critical aspects of the station program that the techniques and requirements of assembly and maintenance must play a large role in determining the design choices.

The planning environment has been quite fluid, a fact which was highlighted by the initial findings of the Fisher- Price group, that the amount of EVA time required for maintenance of Freedom after assembly exceeds that which could reasonably be expected to be available. Nevertheless, the planning proceeded and must proceed.

The general guidelines for going ahead are as follows. First, the complete assembly of the space station will require 18 shuttle missions, stage missions, that is, plus 10 logistic missions, or a total of 28. Both assembly and maintenance will normally be accomplished only when a shuttle is docked at the station, and for four days in each flight, four days out of the seven-day flight.

This amounts to about a twelfth of the total time. This is dictated in part by the fact that EVA during assembly of Freedom will be conducted with shuttle external maneuvering units, which must be shuttle based and ground maintained, and partly by safety considerations. The risk of EVA is reduced by the presence of the shuttle which can maneuver to recover an astronaut or some hardware element which might become detached from the station during assembly or maintenance.

When the station is permanently manned, three EMUs will be carried to enable EVA if necessary from the station. Each of these EVAs should be usable 25 times before ground service.

The next point is that the planning for assembly and maintenance should minimize the use of EVA, replacing it wherever possible with tele-operated or robotic operations. This last guideline represents in the view of my subcommittee a fundamental change in the conceptual basis of space stations relative to the operational concept which had generally been accepted prior to the last restructuring of the program. It appears to us to be connected to, and may even follow from the management decision not to continue development of advanced EMUs, which can be station based.

It also implies a reliance on tele-operation and robotics greater than had been previously been considered feasible.

Dr. Lenoir has already summarized the findings of the external maintenance and task teams . I will deal with that very briefly by noting that first of all, the estimates of required maintenance time are very tentative, because they are based on estimates by the organizations which are building the orbital replacements units, the maintainable elements of the space station, of the maintenance frequency, and the time that is required for each maintenance action.

These estimates are based on their preliminary conceptual designs and so are not hard estimates of a specific piece of hardware. They are probably the best that can be done at this time, however, so the Fisher-Price team has based their estimates on these estimates made by the manufacturers.

What they have done is take the estimated actual work task times, or the time that they believe an astronaut ought to require to do a particular task, and added to it what they call an overhead time, the time that is required to prepare for a task, to disassemble equipment afterwards, and so on. Their estimate of this latter time is about five times the actual work task time. They came up with an overhead factor, as they call it, of six.

Since the original estimate, which was for example, from the first element launched to permanent manned capability, a period of 30 months, there would be required over 6,000 EVA hours or about four two-man EVAs per week in that 30-month period. Again for example after assembly, about 3,000 EVA hours per week would be required.

Since those original estimates, the EMTT has studied the overhead factor in detail and has offered space station management a set of 20 recommendations for design changes which, if implemented, should greatly reduce the overhead EVA times to as low a factor as two times the actual work task hours, instead of a factor of six. Dr. Lenoir has told you that management intends to implement these changes.

The external maintenance task team has also studied the potential for carrying out maintenance actions with space station robots, including after assembly completion, they should be able to perform about half the maintenance tasks without EVA.

To sum up this aspect, the projected change in the overhead from six to two would reduce the required annual EVA from 3,000 hours to about 1,100, shifting half the tasks to the robots would drop the required EVA to a little over 500 EVA hours per year on average. This is very hopeful. The subcommittee notes, however, that the space station robots are actually tele-operators, and I will elaborate on that distinction in just a moment.

While they may reduce the demand for EVA, they are not likely to significantly reduce the demand on crew time, which is the most precious commodity in space station operation as we see it now.

Let me discuss the external maneuvering units for a moment. An external maneuvering unit consists of two principal parts, the space suit itself, then the portable life support system, or backpack. The current plan is to use the shuttle EMU for space station assembly and maintenance. The suit operates at a pressure of 4.3 PSIA, and is individually tailored to fit the crewman by a choice of the size of the upper garment, which is hard, and adjustment of the leg and arm lengths. It requires completely disassembly and refurbishment after three uses, work which must be performed on the ground.

EMUs for the assembly crew will be taken up on the shuttle, used to perform the assembly operations and return to the ground with the crew. If the shuttle cabin is held at normal atmospheric pressure, 14.7 PSIA, during the assembly operation, a four-hour pre-breathe is required prior to depressurization to the 4.3 PSIA level.

However, by reducing the shuttle cabin pressure to 10.2 PSIA, the pre-breathing period can be reduced to 40 minutes, a large gain. Certainly this latter option should be available during the early phases of assembly, both before and after the station is manned. But after assembly is complete, when the station pressure is 14.7 PSIA, the shuttle also will be at 14.7 when it is docked at the station.

So unless a high-pressure suit is available, pre- breathing will be necessary with a three-hour penalty associated with it.

The portable life support system for the shuttle has high consumable requirements. It uses lithium hydroxide to absorb the CO2 from the astronauts respiration. Water is sublimed to a porous plate for cooling. The battery pack requires rather frequent replacement. All of these are acceptable for a ground-maintained, shuttle-based EMU, but probably not acceptable for a station-based EMU.

Ames Research Center and Johnson Space Center have each pursued advanced space suit developments for a number of years. The Ames AX5, the hard suit, is constructed entirely — except for the gloves—of machined aluminum elements with rotary joints. You may have seen pictures of this suit. The Johnson Mark 3 suit has soft elbow and knee sections with shoulder and hip joints similar to those of the AX5.

The subcommittee examined both of these suits closely, and judges them both to be close to a mature design suitable for full-scale development with low risk. Each has some advantages over the other, but either, or a synthesis of either, would be viable as a station-based suit.

There are also viable options for a station based portable life support system, with a much lower consumable demand than the shuttle ELSS. The subcommittee judges that the technology is thus available for a station-based EMU, with low risk.

I should mention that the glove, which has been considered the limiting factor in the suit operating pressure, appears to have been advanced considerably in recent years. An advanced glove is available now which is as easy to use at 8.3 PSIA as the present shuttle gloves are at 4.3 PSIA. So in the subcommittee's judgment the elements are all in place to enable development of the station-based EMU, which could be operated at 8.3 PSIA, eliminating the need for pre-breathing and facilitating EVA from the station.

The cost for developing and procuring such an EMU has been estimated at between $200 and $400 million. It is not presently included in NASA planning until Phase 2 of the station program, which you may recall also includes the dual keel and solar dynamic power.

Let me now describe our understanding of the status of tele-operation and plans for its use. I am using the term tele-operation to distinguish the execution of tasks by humans located remotely from the work place by means of manipulators, from robotics, by which we mean the automatic execution of tasks by autonomous or semi-autonomous robots.

Presently there are no firm plans to use robotics in the assembly or maintenance of the space station, robotics as I have just defined it. Given the rapid development of robotic technologies, it is possible that some level of automation may be available for the space station by the time it is fully operational. However, the present plan is for execution of tasks by astronauts, either in the shuttle or the pressurized volume of the station, using several types of manipulators, or what I have chosen to call tele-operators.

This is an important point, because it follows that the use of tele-operators probably will not reduce the demand on astronaut time for assembly and maintenance. The best estimate the subcommittee has been able to obtain is that the total demand on astronaut time will be about the same, whether a given task is performed by EVA or by tele-operation.

Presently, six tele-operator systems are planned for use in the assembly and maintenance of the space station. I will just describe very briefly those six. There is the shuttle arm, or remote manipulator system, which of course is operational now. There is a space

station remote manipulator system, which is a comparable arm, which would be based on the station instead of the shuttle.

There is a device called the Special Purpose Dexterous Manipulator, and one called a Flight Tele-Robotic Servicer, each of which are dexterous manipulators, which are designed to perform maintenance and assembling tasks. Then there are two astronaut positioning systems, which are arms that position the astronaut so that he or she can perform a task on the station. All of these except the shuttle arm will be based on a platform called the Mobile Transporter, which is capable of moving along the space station truss and around it, so as to position either the astronauts or one of the tele- operators to do a task.

The FTS, for example, will be positioned for task execution by either the shuttle arm, the station arm, or one of these astronaut positioning systems. It is a dexterous manipulator, which in essence as I say replaces an astronaut as the active agent at the end of one of the positioning systems. But it will be operated from a control station, either in the shuttle or in the pressurized volume of the station.

These tele-operators are in various stages of development. The STS arm of course is operational. The FTS is probably next in level of maturity. It will be flown in an evaluation mode hopefully in 1991 in the shuttle.

Task assignments for the dexterous manipulators during assembly and maintenance are still in a state of flux, since the actual capabilities of the FTS and the Special Purpose Dexterous Manipulator are somewhat uncertain. But planning calls for the FTS, at least, to be available from first element launch on, after the evaluation flight in 1991 it is expected that task definition can proceed.

On the basis of these observations, the subcommittee has come to some conclusions and some recommendations, which it has offered to station management, and I would like to summarize those briefly. First, the subcommittee is of the view that Space Station Freedom assembly and maintenance will demand the very best capabilities NASA can muster to accomplish them effectively and efficiently, even though all avenues of pursuit for reducing the frequency of repair actions and their EVA time requirements have been explored.

The uncertainties in the assembly and maintenance requirements, together with the known difficulties of EVA and the relatively undeveloped status of tele-operation technologies would seem to dictate a very cautious planning approach, which maximizes NASA's capability for use of both tele-operation and EVA for these critical tasks.

From this view, current station plan which minimizes the use of EVA, limiting it to that which can be performed from the shuttle with the shuttle EMU, placing a very heavy emphasis on the use of tele-operation, seems to pose considerable risk. Assembly and maintenance capability would be more robust, in the judgment of the subcommittee, if it makes the best possible use of both EVA and tele-operation.

To reduce this risk the subcommittee has suggested that Space Station Freedom management reconsider the development of advanced station-based EMU, which would make available more EVA

time, increase the productivity of the astronauts in EVA, and reduce the time spent in pre-breathe and other activities ancillary to the actual EVA.

The subcommittee recognizes that there are financial implications of such actions which it is not able to include in its consideration. However, it feels that the long-term consequences of the station program may be so serious that management, if necessary in collaboration with the Congress, should carefully reexamine the matter.

As a part of this reexamination, it is recommended that station management take the actions necessary to clearly delineate the risks, costs and advantages of Extra-Vehicular Activity, and develop criteria for its use so that there is a better basis for judging whether any particular assembly or maintenance action should be baselined for EVA or tele-operation.

Mr. Chairman, I wish to close with a personal observation. The difficult assembly and maintenance problems posed by Space Station Freedom should not surprise us. Freedom is the first large structure to be assembled in space. It is in itself an experiment, and the techniques for assembly and maintenance must to some extent be worked out as we proceed.

NASA is doing this with vigor and determination. I believe that with consistent support, Space Station Freedom can be successfully built and will meet the expectations of a large international community which views it as a centerpiece of space activity for the next decade.

I will be pleased to respond to your questions.

[The prepared statement of Dr. Kerrebrock follows:]

1

TESTIMONY OF: PROF. JACK L. KERREBROCK, CHAIRMAN
SUBCOMMITTEE ON EVA AND ROBOTICS,
SPACE STATION ADVISORY COMMITTEE

TO: HOUSE SPACE SCIENCE AND APPLICATIONS
SUBCOMMITTEE

DATE: SEPT 27, 1990

Mr. Nelson, ladies and gentlemen:

My colleagues and I appreciate the opportunity to discuss with you the matters of EVA, robotics, and the capabilities they offer for the assembly and maintenance of Space Station Freedom. The Advisory Committee's activity in this area was initiated by a discussion with Associate Administrator William Lenoir, in which he expressed a desire for the Committee to address a number of questions concerning EVA, EMU's (External Maneuvering Units) and teleoperated and robotic space operations. The Committee judged these to be strongly interrelated subjects. Therefore it established the Subcommittee which I chair, charging it with developing an understanding of these matters and reporting to the parent Committee. These actions preceded by just a month or so the initial release of the findings of the Fisher-Price group concerning the amount of EVA which might be required for assembly and maintenance of Space Station Freedom. These initial findings raised the visibility of the entire set of issues being studied by the Subcommittee. The Subcommittee has continued its study, and presented its findings to the parent Committee at its meeting on August 15, 1990. Today I intend to briefly summarize for you those findings, as refined through discussion with NASA personnel and with the entire Committee at that meeting.

The findings which I wish to present fall into four categories, concerning: 1) the context of planning for SSF assembly and maintenance 2) the relevant findings of the External Maintenance Task Team (Fisher-Price) 3) the status and planning for External Maneuvering Units and 4) the status and planning for use of teleoperators. Finally, I will present some conclusions and some recommendations which have been offered to SSF Management for consideration.

2

CONTEXT OF PLANNING FOR SSF ASSEMBLY AND MAINTENANCE

Planning for the assembly and maintenance of Space Station Freedom has been taking place in a complex and difficult environment. The Station is in preliminary design, with the System Preliminary Design Review to take place in the fall of 1990, so that the planning for assembly must necessarily be tentative, it cannot be finalized until the actual design of the Station components is known. On the other hand, assembly and on-orbit maintenance are such critical aspects of the Station program that the techniques and requirements of assembly and maintenance must play a large role in determining the design choices. Thus the planning environment has been quite fluid, a fact which was highlighted by the initial findings of the Fisher-Price group, that the amount of EVA time required for maintenance of SSF after assembly, exceeded that which could reasonably be expected to be available. Nevertheless, planning has proceeded, within the following general guidelines.

- Complete Assembly of SSF will require 18 stage missions plus 10 logistics missions, for a total of 28 STS missions

- Both assembly and maintenance will normally be accomplished only when a Shuttle is docked at the Station. This amounts to about one-twelfth of the total time. This procedure is dictated in part by the fact that EVA during assembly of Freedom will be conducted with Shuttle EMU's, which must be Shuttle-based and ground-maintained, in part by safety considerations. The risk of EVA is reduced by the presence of a Shuttle, which can maneuver to recover an astronaut or hardware element which might become detached from the Station during assembly or maintenance.

  When the Station is permanently manned, three EMU's will be carried to enable EVA if necessary from the Station. Each EMU will, with planned upgrades, be usable twenty five times before ground servicing.

- The planning for assembly and maintenance should minimize the use of EVA, replacing it wherever possible with teleoperated or robotic operations.

This last guideline represents in the view of the Subcommittee a fundamental change in the conceptual basis of Space Station, relative

to the operational concept which had generally been accepted prior to the last restructuring of the Program. It is clearly connected to, and may even follow from, the management decision not to continue development of an advanced EMU which can be Station-based. It also implies a reliance on teleoperation and robotics which is greater than had previously been considered feasible.

Let me now turn to the findings of the EMTT (Fisher-Price Study Team).

RELEVANT FINDING OF THE EXTERNAL MAINTENANCE TASK TEAM

At the time this report was being prepared the preliminary investigation of the EMTT had been followed by a more extensive investigation, which largely confirmed the preliminary findings, but offered a set of actions which if pursued, would greatly reduce the EVA required for maintenance. The Team based its estimates of EVA requirements on the estimates of repair frequency and repair time prepared by the organizations responsible for the design of the ORU's (orbital replacement units). It did so because the design of the ORU's is not sufficiently mature to enable a more critical, independent judgment of the repair times. To the estimated repair times, the Team added the EVA "overhead time" it estimated to be necessary to set up for the repair, to transport the needed equipment etc., concluding that for each actual EVA worktask hour, six total hours of EVA would be required.

On these bases the EMTT estimated the following maintenance demand for EVA hours:

From First Element Launch to Permanent Manned Capability (30 months)
6267 EVA hours or 4.0 two-man EVA's per week

From Permanent Manned Capability to Assembly Complete (24 months)
5250 EVA hours or 4.2 two-man EVA's per week

Average Annual EVA Demand for Post Assembly Maintenance
3276 EVA hours

The EMTT studied in some detail the "overhead" EVA and has offered to SSF management a set of 20 recommendations for design changes

which if implemented will greatly reduce the "overhead" EVA times, to as low as a factor of 2 times the actual worktask hours instead of a factor of 6. Management has stated its intent to pursue these changes.

The EMTT has also studied the potential for carrying out maintenance actions with the Space Station robots, concluding that after Assembly Complete they should enable performance of about half of the maintenance tasks without EVA.

To sum up, the projected change in the "overhead" from 6 to 2 would reduce the required annual EVA from 3276 to about 1100. Shifting half the tasks to the robots would drop the required EVA to 550 EVA hours per year on the average. The number actually quoted by the EMTT is 507.

The Subcommittee notes that the "Space Station robots" are actually teleoperators, and while they may reduce the demand for EVA, they are not likely to significantly reduce the demand on crew time.

EXTERNAL MANEUVERING UNIT STATUS AND PLANS

The external maneuvering unit consists of two principle parts, the space suit and the portable life support system (PLSS).

As noted above, the current plan is to use the Shuttle EMU for SSF assembly and maintenance. The suit operates at a pressure of 4.3 psia and is individually tailored to fit the crewman, by choice of the size of the Hard Upper Torso (HUT) and by adjustment of the leg and arm lengths. It requires complete disassembly and refurbishment after three uses, work which must be performed on the ground. The EMU's for the assembly crew will be taken up on the shuttle, used to perform the assembly operations, and returned to the ground with the crew. If the shuttle cabin is held at 14.7 psia during the assembly operation, a 4-hour pre-breathe is required prior to depressurization to the 4.3 psia level. However, by reducing the shuttle cabin pressure to 10.2 psia, the pre-breathing period can be reduced to 40 minutes. Certainly this latter option should be available during the early phases of assembly, both before and after the Station is manned. But after Assembly Complete, when the Station pressure is 14.7 psia, the docked shuttle too will be at 14.7 psia, so that unless a high pressure suit is available, prebreathing will be necessary.

The PLSS for the shuttle EMU has high consumable requirements. It uses LiOH to absorb the CO_2 from the astronauts' respiration. Water is sublimed from a porous plate for cooling. The battery pack requires rather frequent replacement. While all of these are acceptable for a ground-maintained, shuttle-based EMU, they are probably not acceptable for a station based EMU.

Ames Research Center and Johnson Space Flight Center have each pursued advanced space suit developments for a number of years. The Ames AX-5 is a hard suit, constructed entirely (except for the gloves) of machined aluminum elements with rotary joints. The Johnson Mark III suit has soft elbow and knee sections, but shoulder and hip joints similar to those of the AX-5. The Subcommittee examined both of these suits closely, and judges them both to be close to mature designs, suitable for full scale development with low risk. Each has some advantages over the other, but either, or a synthesis of them, would be viable as a Station-based suit.

There are also viable options for a Station-based PLSS with a much lower consumable demand than the shuttle PLSS. Adsorption-desorption systems are available for CO_2 removal, and radiator systems can be implemented for cooling, eliminating two of the largest demands for consumables. The Subcommittee judges that the technology is thus available for a Station-based PLSS, also with low risk.

The glove has been considered the factor limiting suit operating pressure. A steady refinement has now resulted in gloves which are as easy to use at 8.3 psia as the present shuttle EMU gloves are at 4.3 psia.

Thus, in the Subcommittee's judgment, the elements are all in place to enable the development of a station-based EMU which could be operated at 8.3 psia, eliminating the need for pre-breathing, and facilitating EVA from the Station. The cost for developing and procuring such an EMU has been estimated at $200 to $400 M. It is not presently included in NASA planning until Phase II of the Station program, which also includes the Dual Keel and Solar Dynamic Power.

6

TELEOPERATION STATUS AND PLANS

I will use the term teleoperation to distinguish the execution of tasks by humans, located remotely from the work place, by means of manipulators, from robotics, by which we mean the automatic execution of tasks by autonomous or semi-autonomous robots. Presently there are no firm plans to use robotics in the assembly or maintenance of Space Station. Given the rapid development in robotic technologies, it is possible that some level of automation may be available for Space Station by the time it is fully operational, however the present planning is for execution of tasks by astronauts, either in the shuttle or in the pressurized volume of the Station, using several types of manipulators, or teleoperators.

This is an important point, because it follows that the use of teleoperators probably will not reduce the demand on astronaut time for assembly and maintenance. The best estimate the Subcommittee has been able to obtain is that the total demand on astronaut time will be about the same, whether a given task is performed by EVA or by teleoperation. If EVA is used the actual task execution time will be comparatively small, but the EVA "overhead", the need for an observer inside the Station, the pre-breathe, etc. increase the total demand on astronaut time considerably. In the case of teleoperation, these ancillary requirements are reduced or eliminated, but the time required to actually complete a given task is larger, because of the difficulty of teleoperated manipulation. The Subcommittee was told furthermore, that the operators find the manipulation of the teleoperators very demanding, that they are quite exhausted after a long session at the control station. There is the possibility of teleoperation from ground stations, but at the present time the uncertainties connected with communication time delay and with the gaps in communication via TDRS dictate against reliance on this mode.

Presently six teleoperator systems are planned for use in the assembly and maintenance of SSF.

- The Shuttle Remote Manipulator System (STS RMS)
- The Space Station Remote Manipulator System (SSRMS)
- The Special Purpose Dextrous Manipulator (SPDM)
- Two Astronaut Positioning Systems (APS)
- The Flight Telerobotic Servicer (FTS)

All of these except the STS RMS will be based on a platform called the Mobile Transporter (MT), which is capable of moving along the Space Station truss, and also of moving from one face of the truss to another. The two APS will be used to position the astronauts, one giving access to each side of the truss. The FTS will be positioned for task execution by the STS RMS, or the SSRMS or one of the APS. It is a dextrous manipulator, which in essence replaces an astronaut as the active agent at the end of one of the positioning systems. It will be operated from a control station in the shuttle or in the Station pressurized volume. As far as the Subcommittee was able to learn, the SPDM has essentially the same role as the FTS.

These teleoperators are in various stages of development. The STS RMS is of course operational. The FTS is probably next in level of maturity. It will be flown in an evaluation mode on the shuttle during 1991. Task assignments for the dextrous manipulators during assembly and maintenance are still in a state of flux, since the actual capabilities of the FTS and SPDM are somewhat uncertain. Planning calls for the FTS to be available from First Element Launch on, however, and after the evaluation flight in 1991, it is expected that task definition can proceed.

There are ongoing research and technology efforts aimed at advancing the agency's capability in robotics and automation. One such effort which came to the Subcommittee's attention is that directed at an Autonomous EVA-Retriever at Johnson Space Center. The mission of this device is to autonomously recover and return to the Space Station an object which becomes detached from the Station and is drifting into space. It is in the early R&T phase, where successful recoveries are sometimes achieved on an air-bearing simulator table. Given the difficulty of the task, this is very encouraging. Clearly it will be several years, however, before the technology has matured to the extent that a space-rated system can be designed.

CONCLUSIONS AND RECOMMENDATIONS PRESENTED TO SSF MANAGEMENT

1) The Subcommittee has come to the view that SSF assembly and maintenance will demand the very best capabilities that NASA can muster to accomplish them effectively and efficiently even though all avenues are pursued for reducing the frequency of repair actions

and their EVA time requirements. The uncertainties in the assembly and maintenance requirements, together with the known difficulties of EVA and the relatively undeveloped status of teleoperation technologies would seem to dictate a very cautious planning approach which maximizes NASA's capability for use of both teleoperation and EVA for these critical tasks. From this view, the current SSF plan, which minimizes the use of EVA, limiting it to that which can be performed from the shuttle with the shuttle EMU, and placing a heavy emphasis on the use of teleoperation, seems to pose considerable risk. The assembly and maintenance capability would in the judgment of the Subcommittee be more robust if it makes the best possible use of both EVA and teleoperation.

2) To reduce the risk, the Subcommittee has suggested that SSF management reconsider the development of an advanced Station-basable EMU, which would make available more EVA time, increase the productivity of the astronauts in EVA, and reduce the time spent in pre-breathe and other activities ancillary to the actual EVA. The subcommittee recognizes that there are financial implications to such action which it is not able to include in its considerations, however it feels the long term consequences to the SSF program may be so serious that management, if necessary in collaboration with the Congress, should carefully reexamine this matter.

3) As a part of this reexamination, it was recommended that the SSF management take the actions necessary to clearly delineate the risks, costs and advantages of EVA, and develop criteria for its use, so that there is a better basis for judging whether any particular assembly or maintenance action should be baselined for EVA or for teleoperation.

4) The Subcommittee had the definite impression that there has been a lack of coordination between the several groups developing teleoperators, and between these groups and the design teams who are responsible for determining how the teleoperators are to be used in assembly and maintenance. While a certain degree of indefiniteness is natural at this time because the hardware is in the preliminary design phase and the teleoperators are also still in their early phases, the Subcommittee believed that stronger coordination at Level II was needed. This situation will be greatly improved by the recent establishment of a single point of responsibility for Space Station Teleoperation at Level II in Reston.

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CONCLUDING REMARKS

Mr. Chairman, I wish to close with a personal observation, that the difficult assembly and maintenance problems posed by SSF should not surprise us. SSF, as the first large structure to be assembled in space, is in itself an experiment, and the techniques for assembly and maintenance must to some extent be worked out as we proceed. NASA is doing this with vigor and determination. I believe that with consistent support SSF can be successfully built and will meet the expectations of a large international community which views it as the centerpiece of space activities for the next two decades.

I will be pleased to respond to your questions.

Mr. NELSON. Thank you. Thank all of you for your testimony.

With the indulgence of the committee, what I propose is that I am going to ask a couple of questions to get us started here. I will turn it over to the members, then the Chair will interject as the discussion flows. But I want the members to have the opportunity to get into this. We will proceed on that basis.

I want to ask a question of you, Dr. Kerrebrock, and then get Dr. Lenoir to comment. In your testimony, you said in the last couple of minutes that from this view, the current station plan, which minimizes the use of EVA, limiting it to that which can be performed from the shuttle with the shuttle EMU, which is the soft suit, and placing a heavy emphasis on the use of tele-operations, seems to pose considerable risk.

What is the nature of that risk?

Dr. KERREBROCK. Well, the risk perceived by my subcommittee is that exigencies in the assembly or after assembly in the maintenance will arise, which will be difficult to respond to within the time and ability limitations that are set by the requirements which I have outlined for primarily using the suit from the shuttle within the limited time the shuttle is based at the station.

These are ameliorated to some extent by the intent to have suits on the station. I don't mean to confuse that issue. There will be suits based on the station, but they will not be used normally for maintenance or assembly activities. The normal activities will take place from the shuttle.

So the planning is to do the assembly and the maintenance within the limited time window that is available when the shuttle is docked at the station. Now if unexpected assembly tasks arise, or unexpected maintenance tasks beyond those which can fit into this time period arise, our perception is that it will be more difficult to respond to these with tele-operation than with EVA. EVA is probably the more robust concept in terms of being suitable for ad hoc planning of these activities.

Mr. NELSON. So you are saying that the four hours pre- breathe and the four hours after the EVA, all of that in order to accommodate the soft suit—I will refer to it as the soft suit—that that along with the uncertainty about the tele- operated system and/or the excessive crew time involved with the tele-operated system, you are saying that's what all comes together to add to unacceptable risk in the overall functioning of the station.

Is that a fair summary?

Dr. KERREBROCK. Yes, sir. But beyond that, then, there is the possibility of reducing that risk by having available a hard suit which can be station based, and which would facilitate EVA activities, and enable a more robust response to unexpected requirements. This is the central point.

Mr. NELSON. Dr. Lenoir, could you comment on that, please?

Dr. LENOIR. Yes. I don't want to take issue with any of Professor Kerrebrock's conclusions. They are basically our conclusions as well. As you know, we do not have an advanced space suit in the space station program any longer because we do not have the funds to support it. It is as simple as that.

In the long run, we would like an advanced space suit. We will need an advanced space suit for exploration, as well as for the long term operation of the space station.

In the interim, with the lack of money, we have some alternatives that we are looking at. We have a space shuttle suit that can function and as Professor Kerrebrock mentioned, we plan to do those EVAs while the shuttle is there. We don't have to, but we plan to, because it is more convenient. The shuttle is there, not so much the presence of the shuttle, but the addition of seven more crew members.

So if I have permanently manned and I have either four or eight people living on a space station, I have an additional four crew members that are coming up for their rotation as well as the three in the shuttle crew that can be used to perform EVAs while the rest of the crew continues to do their user work on the station.

That's a fallback, and that's our plan. When we look at the numbers, they work. When we look at the amount of hours available from a shuttle during a shuttle assembly flight, we have allocated half of those EVA hours to the assembly sequence. So when we say particular assembly flight is tight on EVA hours, we mean it is tight fitting within half of our total, because we have not allocated the rest of the reserve.

Another thing that can be looked at to help our problem is reduced pressure, as Professor Kerrebrock mentioned, 10 PSI, 10 pounds per square inch, essentially eliminates the need for prebreathe. It requires maybe 40 minutes or so, but as you well know, when you are suiting up and checking out the suit, it takes you that long to get ready anyhow. So that is almost for free. That is a potential short-term fix.

Regarding upgrading the space shuttle suit, early in its development we had a requirement that after three uses it had to be torn down and rebuilt on the ground. We have now certified it for six uses. We are in the process of certifying it for 12 uses, and before the space station first assembly flight occurs, we intend to have the space station suit certified for 24 uses prior to requiring ground-based maintenance.

So we think that while that may not be our first choice, we have an adequate "it will work" scheme in place. When we look at an advanced suit, we must look not only at the engineering and whether the technology is possible to build this suit, but a real system is a space suit wrapped around a human being. It is that combination that does the activities. So we must ask the operators about the acceptability of the suit.

Looking at both the Mark 3 and the AX5 prototype suits, and asking the astronauts that have done an extensive series of tests on these in the water tank, playing one off against the other, to mentally pick the best features of each and mentally build that composite suit, now tell me about the acceptability of that resultant suit.

Even there we have two areas we feel are not up to what our requirements are. The gloves, while they have gotten much better, are not totally acceptable yet. We do have the current 8 PSI design and we intend to fly it and test those on the STS 37 mission next spring. With the shuttle space suit, however, we will only be able

to pressurize it to 4.3 PSI, but we will understand some of their dexterity.

The other area of shortcoming with both the AX5 and the Mark 3 is in the waist and the mobility. The bending and rotating is not up to what we would like it to be. That does not mean that an advanced suit is no go. That just means we have a little bit more development to do. In the budget for aeronautics exploration and technology, there is money that is proposed for advanced space suit technology development.

Arnie Aldrich and I talk frequently about that, and the intent is to develop that technology and feed it into the suit. In the meantime, we will be certifying a space shuttle suit for 24 missions, and also finding out how to make it better so that it gets closer to our requirements.

Mr. NELSON. How much would the hard suit cost?

Dr. LENOIR. We have numbers in our program—it was—

Mr. KOHRS. The number we submitted to the subcommittee previously was $352 million, but that included what we call the E2, which is the hard suit plus the backpack. If I recall, that submittal was for 21 suits and seven backpacks.

Mr. NELSON. And that's what you're saying you just don't have enough money for?

Mr. KOHRS. That's correct.

Mr. NELSON. The development of the hard suit—even though you would prefer to have that?

Dr. LENOIR. I would like to have that, yes. I must caution you, though, even if we had the money, because of a desire to increase our technological capability in those two areas, gloves and waist mobility, we probably could not make the assembly sequence readiness in any event, so that forcing our attention to the operational phase is probably the right approach.

Mr. NELSON. Well, how do you square, Dr. Lenoir, this conclusion, much of which, as you say, has been budgetarily driven, with the report of the Fisher-Price study where there was a rebellion in your ranks with regard to the excessive EVA time that ought to be required on the station?

Dr. LENOIR. I think most of that rebellion was focusing on the original numbers which indicated that perhaps as many as five EVAs a week would be required, and the crew looked at that and said "We can't do that with this suit, we need a better suit." Mr. Kohrs and I looked at the same numbers and said "We can't do that, period. It is not a matter of a new suit, but we are not going to be doing five EVAs a week."

Now that we are down to somewhere between one EVA a week or one EVA every other week, the crew, and in particular the part of the astronaut office that is responsible for the EVA portion of the operations, believes that the system we have and our plans for using the space shuttle suit through the assembly sequence is viable and does work. That does mean that they would not prefer to have to pre-breathe.

Mr. NELSON. You are confident in your statement that you are down to one EVA? What did you just say?

Dr. LENOIR. Our current numbers—actually not our current numbers, but one iteration back—is about one every eight to ten

days. Our most recent updates that come from external simplifications, solving the weight and power, have removed boxes from outside. If it's not out there, I don't ever have to maintain it. Our most recent numbers don't include those effects yet.

Mr. NELSON. Dr. Kerrebrock, the one EVA every eight to ten days, how did your subcommittee feel about the likelihood of that on this configuration of the space station?

Dr. KERREBROCK. I think our central concern is that all of these numbers are based on conceptual designs, preliminary designs and estimates from those conceptual designs of failure rates, and maintenance times or repair times, should there be a failure. All of those are subject to large uncertainty at this time. They will be subject to large uncertainty right up until the time we have detailed design, actual designs of the devices that will be used in manufacturing.

Even after that, many of the critical components of the space station are in a sense experimental. They are one of a kind, and first of a kind in some sense. So the failure rates and repair times will always be somewhat indefinite. NASA is doing a very thorough, conscientious job of trying to estimate these requirements as best they can, given all of these facts. But fundamentally, they are very uncertain, and will be, until the station is up there and operating.

Our feeling is that it is not wise to cut it too fine on the basis of these preliminary estimates, but it is better to be conservative, as I said, in planning the capability for responding to unexpected problems during assembly or unexpected maintenance. That is, I think, the basic point. We need a reserve there, and the advanced space suit with its facilitation of EVA offers that reserve.

Did I answer your question?

Mr. NELSON. Yes. But we are going to get back into this some more a little later. I want to give the other members a chance. When Mr. Rhodes gets back, we will turn to him. In the meantime, Mr. Packard?

Mr. PACKARD. Thank you, Mr. Chairman.

Dr. Lenoir, are there several subcommittees such as the one that Dr. Kerrebrock has been chairing that are working on other aspects of the space station?

Dr. LENOIR. Yes. Let me say a few things to give you more of the details. As Professor Kerrebrock mentioned, we have a NASA Space Station Advisory Committee. We specifically asked the chairman to see if he was interested or would be willing to focus on some key areas where we really sought external advice, rather than trying to be fairly thin, but across the whole program. The EVA issue was one, the orbital debris issue was another. I believe verification was a third. We asked about a fourth that turned out to be not practical.

How about a quick statement, Dick?

Mr. KOHRS. The NASA advisory subgroup, Larry Adams chairs that, and Dr. Kerrebrock chairs the EVA robotics, Tom Young chairs the systems verification subgroup, and Dr. Ed Crawley chairs the Debris Protection Subgroup. They reported back formally to their panel and to me within the last month. I think I can speak for Tom Young and Dr. Crawley. They are endorsing what we are doing on the systems verification activity, and endorsing

what we are doing on the debris protection. That is something that will continue over the next months. And then Dr. Kerrebrock heads the EVA robotics activity.

Mr. PACKARD. Is there anything in Dr. Kerrebrock's subcommittee report that gives you concern or that you feel would justify or would suggest revising your design criteria?

Dr. LENOIR. I would say the draft report that I have seen and of course, Professor Kerrebrock can correct me if he disagrees, my reaction is that it largely concurs with our approach, given our ground rules, and given our constraints that we have. While it does identify several areas of concern, they are the same areas of concern we already had. So it does not cause new concern, it amplifies that we have the right worries.

Mr. PACKARD. Dr. Kerrebrock, do you concur that the things you have researched and reported, are they opening up new areas of concern, or essentially is the existing design of the space station addressing those concerns adequately?

Dr. KERREBROCK. It is the program that is really under discussion, more than the design. What we have done is identify an opportunity for making the program in our view more robust with regard to assembly and maintenance, but by adding an element to the program which is not there now, the full-scale development and deployment of a more advanced space suit, which would facilitate EVA.

As I said, the committee recognizes that there are financial tradeoffs within the program that it really has no way of adjudicating. We certainly do not want to fault the decision that has been made by NASA within its present funding limitation. That is something that Dr. Lenoir and Mr. Kohrs have to do. We can't do that.

Mr. PACKARD. Any of the other committees that have reported to you thus far, have they opened up any new concerns or recommended some changes?

Dr. LENOIR. No, no new concerns. The Aerospace Safety Advisory Panel did have a preliminary concern dealing with the use of the shuttle suit in the space station assembly phase, and subsequent to that we found out that they were working on data that was not up to date. We asked the key member to go to the Johnson Space Center and arrange briefings from the space suit contingents there to bring him up to date, and he reported he was happy and was not concerned from the point of view that the Aerospace Safety Advisory Panel would take.

Mr. PACKARD. If funding is cut back significantly through one process or another of the budget, do you have contingency plans? Do you have different benchmark plans relative to the level of funding?

Dr. LENOIR. No, I would say that contingency plans may imply a definitiveness that is not here yet. The range of cutbacks from $195 million from the House appropriations to $867 million, I believe it is, from the Senate appropriation, and several intermediate steps in between, all have different answers.

Yes, we have looked at it; yes, we do have a shopping list of some things that we could do individually or taken jointly in order to save some money. We don't have firm figures yet that would make us comfortable talking about what they would be. But the general

strategy is, as we mentioned last year, to remove any content we can that is not absolutely essential to the initial mission of the space station facility. There is not much left, because most of that we took out last year.

Mr. PACKARD. Dr. Kerrebrock, from your review, if funding is cut back, that would require some adjustments. Would you suggest adjusting the schedule, or would you suggest reducing further content of the project?

Dr. KERREBROCK. I don't think I am in a position to answer that question. That requires complete understanding of the program, and all of the aspects, the international aspects, for example.

Mr. PACKARD. Dr. Lenoir, you just spoke briefly to cutting content to the bone. If that does not suffice, are there other content areas that you would look at, or would you look at adjusting the schedule?

Dr. LENOIR. Then we would have to look at adjusting the schedule. Our strategy is two-phased there, to try to identify some aspects, for example the full-up manning we could delay in such a way that it would not exorbitantly run up the run-out costs. Our feeling is that that does not get us all the way there, even in the $200 million cut.

But beyond that, it is delaying certain pieces of it or the entire space station. Our number one priority would be trying to hold the first assembly flight, if not to March 1995, as early as we possibly can, because we think it is absolutely vital to demonstrate that we are in fact capable of building this space station and to demonstrate that by beginning to put it into orbit.

But our first assessment says that when we defer things due to schedule, to get schedule due to a shortfall, for every $100 million I save this year, before I am finished, because of the inefficiencies, it will probably cost me $300 to $500 million in run-out costs.

Mr. PACKARD. By extending the schedule?

Dr. LENOIR. Yes, by extending the schedule.

Mr. PACKARD. Thank you, Mr. Chairman.

Mr. NELSON. Mr. Rhodes?

Mr. RHODES. Thank you, Mr. Chairman. Before I begin to ask a few questions, I would like to associate myself with your opening remarks, both as they relate to budget problems and to the support of at least this member of the subcommittee for this program. I think you pinpointed some very severe problems that we have.

I would like to address the weight and power issues. First of all, we have fairly significant overruns, I guess you would call them, in both areas. Can you outline for us how those overruns occurred, in what areas we got overweight and under power?

Dr. LENOIR. Let me give a summary of that, and then I will ask Dick Kohrs to dig in and give you a little more specifics.

Mr. RHODES. Can you also tell us if there is a relationship between overruns in weight and power?

Dr. LENOIR. The relationship is not direct. It is what I would say an indirect relationship in that we did not, several years ago, have the vigor and rigor in our engineering process that we should have to worry about that as soon as we should have that. It's partly driven by an instability in the program. It is hard to stay up on top of your weight allocations, or even know what they are, and your

power allocations, when the configuration is changing every year due to the budget not being quite what you thought it was going to be.

But that's really how we got there. It is not that we put the allocations in and then got very high over them, it is that we did not have allocations as early as we should have, part of our systems engineering process. I say that with full hindsight. If we were back in that time frame, it would probably be very difficult, given the reality of the program that existed in those days, to have done it much differently.

So we had some changes that hit us year to year, and we never quite caught up in our systems engineering process until last summer, when we began to insist that it was time, we were becoming a real program, hardware is our product, we must have those allocations at the work package level, and we must be able to rack up where we think we are versus those requirements.

Mr. KOHRS. I could go into detail in each of those areas, but last November, when we had gone through our configuration budget review, when we adjusted the program, we came up with an assembly sequence that took 18 assembly flights and 10 logistics flights. That equated out to about 512,000 pounds in shuttle payload capability. We set allocations to each of the work packages, then the PDR process started at the work package level.

If you go back and look at when we highlighted our weight and power growth, it was a result of the preliminary design reviews occurring at the work package and subcontractor level, where they now were bringing forth their preliminary drawings. We use a terminology of weighing the drawings, determining how much each component weighs. Adding all those up came out way above our allocation.

We established terminology—this was to both to weight and power—we established a team which has the name Turbo Team, which has worked extensively since the May time frame that has now driven these numbers back, as Dr. Lenoir mentioned, very close to our original allocations. The original allocations essentially say that from a weight standpoint, we can probably put the same assembly up in the 28 flights, and from a power standpoint, we meet our 45 kilowatts housekeeping and 30 kilowatts of power for the users.

In terms of where the weight growth and power growth occurred, it was pretty much uniform across all the work packages, primarily work package one and two. Work package one was Marshall-Boeing, work package two was Johnson- McDonnell Douglas. Work package three, which is Goddard, the Flight TeleRobotic Martin Marietta Company, and the General Electric Company, will work pretty much on course. The power supplier, Lewis and Rocketdyne, was on course on power. Their weight was up somewhat.

But if you look at the way we reported this to the staff over the last two or three months, you see a steady decline of decisions we have made to get the weight out and the power back down. The decisions come in about four different categories: just mistakes or bookkeeping errors, which are easy to find. We do double bookkeeping between work packages, those are pretty small differences. Duty cycles on how long things are run. Some things were run all

the time, and really should have been cycled, things like ovens, dishwashers, freezers; we solved those easily by getting a realistic duty cycle. T.V. cameras is another example.

Where we made the big weight reductions was primarily in looking at detail from a systems integration standpoint to make sure we had consistency across all of our work systems from work package to work package to work package. We found that in redundant systems, some of the work packages were put in redundancy within redundant systems.

From a program standpoint, to meet the criteria of one fault tolerant, or one leg of redundancy, we went back and took out redundant pumps, redundant electronics boxes, and did that over this two or three month time frame. We have curves to show you that we systematically brought it back.

In doing this, we had the full participation of our international partners and the full participation of the user community, and we don't think we have compromised the international partner interface or the user interface.

Mr. NELSON. You say you have your weight down three percent over the baseline. For conservative planning, shouldn't you get it down to 10 to 20 percent below the baseline to allow for the growth?

Mr. KOHRS. Yes, and in our allocation, there is a five percent margin. So in this 512,000 number, the program has held back a five percent margin. But you are right. We need to get the weight down below that, and we need to get the power down below the 45 kilowatts, so we have some margin for growth. The experience in any weight-power EVA is that if you don't stay on it and work it every day of the week with the right people, it is going to tend to grow. You have to constantly make that a daily job, that you are taking out some things and are going to add some things.

Mr. NELSON. That you are taking out some things and going to add some things.

Mr. KOHRS. Yes, that things are going back, and some things will have to be removed.

Dr. LENOIR. For example, if you looked at the specific weight history in work package one, which is the modules, you will find that they got under their allocation, but then you will find as time goes on they keep getting further under it. Having gotten there, they did not stop. Their target is to get 10 percent under their allocation, which would give us a total of 15 percent margin. Each of the work packages is targeting to get under its allocation.

Mr. NELSON. This is probably the point at which to ask a fundamental question. If we avoid sequester, which I think we will, there may be a temporary one, but I can't imagine the Government of the United States going on with a 32 percent reduction while the President here is spending.

So if we avoid the sequester, but if in the budget deliberations and agreement that comes near the Senate appropriations agreement, which is about an $850 million level less than the President's request, as compared to a $200 million less than the President's request in the House appropriation, looking at that kind of cut, are we not—the cut to the President's request is actually an increase over the present year's funding.

But given what you are making the dollars allocate, are you not looking at a major redesign of the space station, and I guess to further elucidate in my question, we had the experience of Skylab, right there, photographed on the wall. We have this design which we are working on. Is there something in between that you would actually have to look to seriously, given the budgetary constraints?

Dr. LENOIR. Yes, we would have to look at that. I might point out that the Senate subcommittee—I guess it is full committee now—appropriated number is actually lower than our fiscal year 1990 operating plant. It is actually a step backwards from where we are today.

But there is no question. We would have to go into some what I would call architectural redesign. We would try hard to do it at the architectural level and maintain some of the component design underneath it. We would have to look at how we supported our various user communities and what are their priorities, and consider deferring the support to the lower priority communities, consider in the microgravity sciences that maybe we are forced into some areas that give them a little bit less space, a little less power, and a microgravity level that is not quite as good, with plans to buy that back as time goes on.

On the life sciences, more of the same. Maybe we cannot afford a centrifuge as large as we are talking about, or as much power, or as much room. Things would get smaller not only in a physical sense, but in the way that they would support our overall requirements. We would try to phase our support to these requirements so that over time—but it would be a much longer time frame—we would eventually meet the requirements we have today, but to begin shortly getting part way there. I think indeed, it would look different.

Mr. NELSON. Would it look something like—well, let me ask this. Would there be the ability to learn from the Soviet space station and what they have achieved, and build on that, given the budgetary constraints?

Dr. LENOIR. We do, of course, keep track of the Soviet experience, and would like to think we have learned from that, from their difficulties, the number of EVAs they do, and how they do it. They really have a different concept, and it is really smaller. When we talk about our space station, with 75 kilowatts of power, their next growth will get them to 20 kilowatts.

We are an order of magnitude different, bigger and better, if you like, than they are. Their support for the user community is nothing like we are talking about doing. Most of their equipment is inside, not outside, because they don't have as much of it.

We have tried to learn from them, at every opportunity we get, and there are more and more of them now, to exchange some thoughts with them.

Mr. RHODES. Well since you have launched the subject of the budget, let me ask a budget follow up question. This relates to what happens when we have the thing up there. Do you have an operational budget for the space station?

Dr. LENOIR. We have a draft of an operational budget that is incomplete as yet, because it will need to be brought fully up to date with the preliminary design completion data. But we have gone

through in-depth and assessed what it will cost us to operate over each of the area of logistics, sustaining engineering, space operations, ground operations, and so on. Some years ago, I think in 1987, we did it, and I think our estimate was $1.5 billion a year. In those year dollars, I believe our numbers are still under that. Although, since they actually happen out in the year 2000, they look a lot larger.

Mr. RHODES. But updating the operational budget will be a part of the PDR process, is that correct?

Dr. LENOIR. Yes, as a matter of fact, we have most of the data in hand. There are just a few loose ends. We have not committed to publishing that until the post-PDR time frame, but we are largely there. I look at it and pushed on us to get it done early, because I anticipated some problems. I am happy to report that I did not find the problems that I anticipated, and that I am convinced that the depth and rigor with which we did it is accurate.

Mr. RHODES. Let's move back to weight and power for just a second.

When the work package contracts were awarded, were weight and power requirements clearly specified in those work package contracts, and are there penalty provisions in those contracts for weight and power overruns?

Dr. LENOIR. No. I believe that while the proposals had weight and power numbers in them, the contracts that we negotiated did not have weight and power numbers. That is part of the problem we have been dealing with this past year, is that when we concluded we did indeed have a problem and we needed to get those numbers into the contract, we had to go about it slowly, because we did not way to pay a lot of money to put them in.

I might say that over the year, we have gotten outstanding cooperation from our contractor community, and we have them in the prime contracts, and are working through the prime contractors to make sure the appropriate subcontractors also are contractually bound.

Mr. RHODES. I would presume that the reductions you have been able to achieve in both weight and power have been done by or in cooperation with contractors. Have you been able to verify the information they are supplying to you as to weight and power reductions being accurate?

Mr. KOHRS. We believe so. The contractors have been an active part of what I described as these Turbo meetings that are being held weekly for the last two and a half or three months. As Dr. Lenoir said, we have now imposed allocated or control weights on the prime contractors and most of those had been down-tiered to their subs. We now have instituted a monthly weight reporting that tiers up from the subs to the prime contractors to NASA so we can maintain a more rigorous control over that activity.

Mr. RHODES. I presume that the 75 kilowatt power limitation is a function of the size of the arrays and the photovoltaic technologies as they currently exist. Is that correct?

Mr. KOHRS. That's correct.

Mr. RHODES. Will your PDR include a review of your power production system, and looking to alternative power production sources other than the arrays?

Dr. LENOIR. The PDR for the photovoltaic power system has been completed at the work package level, and as a part of the integrated PDR that will be done. As far as alternatives go, currently in our budget and in our operating plan, is only to take the solar dynamic up through a concept development. I don't believe as a concept development, we will be doing a rigorous PDR on it, although we will be reviewing it. Then again, funding requires us to set that on the shelf and press forward without it.

Mr. RHODES. Press forward without the panels, is that what you mean?

Dr. LENOIR. We will have the panels, but I don't see solar dynamics, which are the round dishes. They are more efficient. We can add power by buying more of the photovoltaic arrays, which won't cost me any more in development. All I have to do is add to hardware. We would rather not, because that adds drag, which makes us burn up more fuel and is less efficient. Our belief is in going above 75 kilowatts, that the strongly preferred technique is to use solar dynamics. Unfortunately, we do not have money in our budget to develop that beyond concept at this point.

Mr. ROHRABACHER. Dr. Lenoir, perhaps you could tell me, are we still totally dependent on the shuttle system to actually get this thing up?

Dr. LENOIR. Yes.

Mr. ROHRABACHER. Okay. Then I guess the $64,000 question is, the shuttle system doesn't seem to be working. What makes us think the shuttle system is going to be working in the future?

Dr. LENOIR. I had hoped very much to be sitting here today with a mission in orbit. Unfortunately, try as we might, we have not found the source of the major leak in the aft compartment in Columbia. We are confident that Discovery and Atlantis do not have such a leak. Neither has shown any aft compartment leakage in any of its flights. Atlantis did have an external leak, so did Columbia. We believe we repaired it. On our last two tankings of Columbia, we verified that we had eliminated the external leak. Therefore, having done the same thing to Atlantis, we are confident we have eliminated that leak, but we will verify that before we fly.

We feel we do have orbiters that are capable of flight, but I must add that the hydrogen leak situation over the summer, as discouraging as it has been on a system this complex, things like that will happen now and then. I don't think that means every year. I think we are building and will be a reliable robust system, capable of 10 to 12 flights a year, as we are aiming in our objectives right now.

But I think every so often, three years, five years or whatever, we may be hit with a hydrogen leak problem that grounds the whole fleet or one vehicle for some number of months. Six months is probably what this will turn out to be. The space station has requirements that will enable it to at any point in its assembly sequence or in its operational phase to sustain a lack of orbiter vehicle visits over a period of that nature.

We are totally dependent on the space shuttle to assemble and service the space station, primarily because it is a manned system, the space station is, and we require the men. Even though I might put up parts of it in an assembly sense on an expendable launch vehicle, big ones that exist today or big ones that we would like to

have today, I still need to put the people up in order to assemble it. We are totally dependent on the space shuttle for getting people into orbit.

Mr. ROHRABACHER. You are calculating then the actual system, or problems with the shuttle system, will diminish rather than expand, in the future, is that correct?

Mr. LENOIR. I think we are probably seeing pretty much a steady state. I think as we go on, we will find some systems begin to age and wear out, and we have a proposed program to deal with that obsolescence combattance, if you like. We feel we will be able to keep the space shuttle flying for another 20 or 30 years by paying rigorous attention to that. As I said, every now and then there will be something that surprises us, that we did not see coming. But I don't believe it will be anywhere like three years after Challenger. It will be more like six months after a hydrogen leak.

Mr. ROHRABACHER. Then you would suggest that as the system gets older, this is more like an airplane, like a 747. You will have fewer problems because you will have worked out the kinks, as compared to more problems, because the system is wearing out and we have discovered certain systems are not holding up under age.

Dr. LENOIR. We might, it is not clear whether we will have fewer problems or more problems. We might likely have more problems, but our experience will be up, and the actual delay and disruption caused by those problems will be down, because we learn how to deal with them.

Some of the more recent experiences we are running into are that our freon loops in our auxiliary power units in our reaction control system jets, we are experiencing some failures and some problems we had not anticipated when we built them. It is quite clear that we need a different, regular maintenance plan on those, and that once we have that in place and are operating with that in mind, the actual disruptions will be less. We are looking to add new redesigns in some areas to replace some of our more troublesome components.

Mr. ROHRABACHER. Let me just note before I go on to my last subject matter, that I think this is an area of real concern. It is so fundamental to everything else. All the other details, even if we work out all the other details and the shuttle system is not functioning at a much better level than it is today, the project is doomed. So I think this is an area all of us should be concerned about.

One last area I would like to talk about is the space suit situation. I would like to compliment Congressman Mineta for the leadership he has offered in this area. This is also an area where we are trying to keep down the cost, and over the last year there has been a lot of dancing around this issue.

We have certainly tried to make sure we focus on whether or not we need a high-pressure suit. Congressman Mineta has offered some leadership in this, and I have tried to pay attention to it as well, not only for the success of the mission, but also for the success of the taxpayers.

We have determined we will not be having a high pressure suit, you said shuttle-suit. Is this going to take away from the maximum

efficiency that we could have in actually putting this station together?

Dr. LENOIR. Yes, it would be definitely somewhat less efficient. If by efficiency you mean getting there in about the same total period of time, no, I think we will achieve our assembly either way, at about the same point in our schedule.

Mr. ROHRABACHER. We could actually do the job better, however, if we had the high pressure suit.

Dr. LENOIR. That's correct.

Mr. ROHRABACHER. Dr. Kerrebrock, did you say that the AX5, and I believe this was your testimony, actually meets the standards and specifications, except for the gloves and backpack for a high pressure suit, and it could do the job?

Dr. KERREBROCK. Yes, sir. Both the AX5 and the Johnson Mark 3 are prototypes. They are not fully developed. But it was our subcommittee's judgment that they are ready for full-scale development, with relatively low risk. With the glove technology that is available now, our sense was that yes, they could operate at high pressure, and that the facility with hands would be about what it is now with the shuttle suit.

Mr. ROHRABACHER. So the reservation with the AX5 has been the gloves, and of course the backpack as a separate unit. So actually the AX5 is developed, isn't that right?

Dr. KERREBROCK. No, it is a prototype.

Mr. ROHRABACHER. But it is ready for manufacture, so to speak?

Dr. KERREBROCK. It is ready to be developed for full-scale manufacturing. There are refinements that need to go into it before it goes into serial production.

Mr. ROHRABACHER. Are we, in your opinion, deferring the purchase of a relatively inexpensive suit that was developed at a relatively cheap rate, I guess? Are we deferring the purchase of a Ford today in order to buy a Ferrari tomorrow?

Dr. KERREBROCK. I don't think that's the nature of the tradeoff. In our judgment, the ability to have the high pressure suit would add a robustness to the assembly and maintenance procedures, which might turn out to be very valuable in the event that the station is more difficult to assemble than is expected. This may happen, we can't predict it.

Or, in the event the maintenance requirements are larger than we had hoped, we would be able to respond to those exigencies better with the high pressure suit which facilitates EVA.

Mr. ROHRABACHER. I will accept that, and I know Congressman Mineta probably has a few questions on this as well.

Thank you very much, Mr. Chairman.

Mr. NELSON. Mr. Buechner?

Mr. BUECHNER. Thank you very much, Mr. Chairman. Dr. Lenoir, going back to the suit a minute, it is my understanding that the existing suit can be upgraded to an 8 PSI, is that correct?

Dr. LENOIR. Some initial studies indicate that may be the case. I would not go so far as to say that is definitively so, but that is certainly one of the things that must be looked at.

Mr. BUECHNER. I guess my question is, if you get up there, are there other incremental improvements you think could be made off

that? Frankly, are you doing studies on the costs and safety factors of doing that right now?

Dr. LENOIR. Oh, yes. When we talk about the Mark 3 and AX5 suits, I mentioned earlier that the crew does not feel either one is exactly right, but they fit in pieces. It has always been in our mind that we would shop the technology and assemble the best answer, then go build that.

But as we look at that, we look at specific features of each and ask if it is possible and reasonable to think of inserting this technology in our current space shuttle suit. We certainly are doing that and will continue to do that at every step. We will always be looking for the most cost effective solution that gets us the best answer.

Mr. BUECHNER. I know this is early, but at this stage of the game, taking into consideration all the variables, not the least of which is obviously cost down the line, how much we are going to divert to it, but do you consider a modification of the existing suit or the development of a whole new suit as the way we are going?

Dr. LENOIR. I would say the way we are going now, again, driven by the budget constraints we have, is that are modifying our old suit, or in a metaphor not too different from Mr. Rohrabacher's, we are going to continue to drive this car for two more years, not because I want a Ferrari, but because I can't afford a new car right now, and I will get a new car in a few years.

Mr. BUECHNER. Of course, I've seen some of the old Mustangs where people have taken the old engines out and put in new ones, and a new steering system, and they do fairly well.

Going back to the question Congressman Rhodes asked about, a period of time, or maybe Dana asked it, but you are talking about perhaps in six months, they would be independent, their survivability. I guess the problem, though, is not survivability up in the station without the shuttle coming up, but how many times do you think you can throw back the schedule?

If it is going to be built in components, it is not just the issue of the people being able to survive up there, but you really do backlog all your construction, isn't that correct?

Dr. LENOIR. Yes, that's true. It is not just the survivability of the people, but of course, you want the hardware to still be there, and not have reentered by the time you get to it. That is measured in years, based on our requirements.

But you are absolutely right. We want to do it on the schedule we lay out, because if we don't everything backs up.

Mr. BUECHNER. On the schedule you lay out, you obviously have a window you think certain things should be put on and added together. If you go beyond that window because of a shuttle problem, are there any studies you have done that might show that various elbows or couplings would degenerate in outer space if there was not the attachment of the new module that was the next one up in line?

For instance, it should be done in a month, and you are going to do it in six months—is there going to be a degradation of the integrity of that material?

Dr. LENOIR. I understand what you are saying. No, we have not identified anything like that. We require each stage of our assem-

bly to in and of its own right be a viable space vehicle, in the event what you have described were to happen.

Mr. BUECHNER. Mr. Chairman, I am going to yield back. I thank you very much, and I know Mr. Mineta will probably elucidate some more answers on the space suit. But I would just encourage NASA to continue to take a look at utilizing studies possible to make sure we don't just go out and try to invent a new wheel, that we build upon the one we already have. Of course, the main thing is to make sure that our astronauts are safe, and they can perform the mission we are assigning to them.

Thank you.

Mr. NELSON. Thank you, Mr. Buechner.

Mr. Mineta?

Mr. MINETA. Mr. Chairman, I want to congratulate you on your leadership in holding this hearing on Space Station PDR, and I ask unanimous consent for filing my written statement.

Mr. NELSON. Without objection.

[The prepared statement of Mr. Mineta follows:]

SEPTEMBER 27, 1990
NORMAN Y. MINETA, M.C.

NORMAN Y. MINETA, M.C.

MR. CHAIRMAN, I CONGRATULATE YOU ON YOUR FORESIGHT ON HOLDING THIS HEARING ON THE SPACE STATION FREEDOM PRELIMINARY DESIGN REVIEW.

NASA AND OUR SPACE PROGRAM HAVE INSPIRED TWO FULL GENERATIONS OF AMERICANS. SPACE EXPLORATION HAS SERVED AS A VEHICLE FOR INVESTMENT IN TECHNOLOGY, BOLSTERED OUR ECONOMY, ENHANCED OUR WORLD COMPETITIVENESS, AND IMPROVED OUR NATIONAL SECURITY.

IT IS NO COINCIDENCE THAT THE GROWTH AND EXPANSION OF OUR NATION'S HIGH-TECHNOLOGY INDUSTRIES HAVE PARALLELED THE YEARS OF NASA'S GREATEST ACTIVITY AND ACCOMPLISHMENT.

SPACE STATION FREEDOM REPRESENTS THE CULMINATION OF OUR EFFORTS IN OUTER SPACE AND IS A CRITICAL ELEMENT TO OUR FUTURE SPACE ACTIVITIES.

ONE OF THE HOTTEST AND MOST CRITICAL DEBATES NOW UNDERWAY IN WASHINGTON CENTERS ABOUT THE SUM AND SUBSTANCE OF OUR SPACE PROGRAM.

AS A STRONG SUPPORTER OF THE SPACE STATION PROGRAM, I WAS DISHEARTENED TO SEE THE PROGRAM VIRTUALLY EVISCERATED BY THE SENATE APPROPRIATIONS COMMITTEE. I BELIEVE THAT IT IS INCUMBENT ON THE LEGISLATORS WHO DECIDE TO FATE OF THE PROGRAM TO CONTINUE TO FULLY SUPPORT THE PROGRAM IF THE U.S. SPACE PROGRAM IS TO OVERCOME RECENT SETBACKS AND REACH ITS POTENTIAL.

IT IS OUR DUTY AS DRAFTERS OF THE NATION'S SPACE POLICY TO ESTABLISH A REALISTIC, LONG-TERM PLAN THAT HAS THE SUPPORT OF THE AMERICAN PEOPLE.

FOR THIS COMMITTEE AND CONGRESS THE CHALLENGE IS TO CONTINUE TO SUPPORT NASA WITH THE BUDGETARY RESOURCES NEEDED TO ACCOMPLISH THE AMBITIOUS MISSION WE HAVE SET THEM TO. FOR NASA, THE CHALLENGE IS TO MEET ITS TECHNOLOGICAL AND OPERATIONAL GOALS AND TO REFRAIN FROM LETTING COST CONSTRAINTS DRIVE PROGRAMMATIC DECISIONS.

WITH HARD WORK BY NASA AND THE COMMITMENT OF THIS COMMITTEE AND CONGRESS AS A WHOLE, SPACE STATION FREEDOM WILL BECOME A REALITY.

THANK YOU.

Mr. MINETA. Mr. Chairman, the space station is important. It is important to the United States space program, and it is important for the advancements it will bring in many areas. It is important to the United States' technological competitiveness internationally.

However, there are some issues that have been identified again and again as problematic to the space station program. So this PDR is an opportunity for NASA to examine its progress and make necessary design revisions. That's your job.

Our job on this committee is to review NASA's space station program activities. Frankly, I have some concerns.

Estimates for external maintenance of the station have escalated. The final report of the Fisher-Price team raised the number of EVA hours required from 2,300 per year to 3,300 per year. The most troubling finding was that 6,300 hours of maintenance would be required prior to assembly completion. Now NASA has indicated that it would reduce the amount with robotics, but has not indicated how it will reduce the amount of maintenance required during the assembly phase, and the capabilities of robotics are uncertain.

Now we have Dr. Kerrebrock's subcommittee on EVA and Robotics confirming the earlier studies recommending that Space Station Freedom management should reconsider the development of an advanced space station EMU.

So, Dr. Lenoir, I would like to find out, and have you explain, how, in the face of the continued recommendations to the contrary, you can continue to argue against the need for the advanced space suit. I understand there are financial implications to the decision, yet I wonder whether costs or whether programmatic requirements are driving the program.

I have participated in several hours of briefings. Dick Kohrs was kind enough to come by the office, and I have been in hearings and private conversations with NASA personnel on this issue. I have yet to see any data that gives me confidence that you can operate a space station without an advanced space suit.

This leads me to believe that cost constraints are indeed driving the program. However, I would remind you that last week this committee recommended that an advanced space suit be required for the operational space station. I will echo the conclusions and recommendations presented to space station management, and Dr. Kerrebrock's testimony. The long-term consequences of refusing to reconsider the development of an advanced space suit to the Space Station Freedom program may be so serious that it is necessary for the space station management to reexamine this matter.

Dr. Kerrebrock's study recommends, and I concur, that you should work in collaboration with the Congress to reexamine this matter. I am really pleased to have you here, so that we are able to hear your thoughts on how we can work together to reexamine the space suit issue.

Dr. Lenoir, I would like to ask you, given what this committee voted last week to recommend, that is that NASA provide us with a study on the results of testing of the Mark 3 suit and the AX5 suit, as well as the current status of all EVA system development activities, including any testing and analyses relating to upgrading the existing shuttle suit, as to whether—or do you have any plans to pursue this request?

Dr. LENOIR. Yes. As a matter of fact that is a continuation of what we have been doing as we have gone through the past several years. As I mentioned, several of our astronauts, under the leadership of Jerry Ross, who has performed an EVA in space and is scheduled to perform another one in the spring time frame, led a team of astronauts that reviewed, critiqued, compared and contrasted the AX5, the Mark 3 and the current space shuttle suit.

I might also add for that matter, that several of our astronauts recently visited the Soviet Union. Jerry Ross had an opportunity to get in the Soviet space suit, so that he could look for anything there that we may not have been aware of. We continue to review the available technology from all the available advanced technology suits, such as AX5 and Mark 3, and see where we think we have accomplished what we need, and where we are not quite there yet.

As I mentioned earlier, there are two or three areas where we are not quite there yet. Waist mobility in the high pressure suit in either the Mark 3 or the AX5 is not currently judged to be operationally acceptable. Part of that is driven by the back entry, which makes it easier to get in and out. But the ease of getting in and out is not sufficient to take constrained waist mobility. These operational concerns need to be dealt with and met.

Our plan is through research funding to make sure we are investigating advanced high pressure suit technologies to bring these up to date. Our intent is to design and develop a high pressure suit as soon as the technology is in place and we have the budget to do it.

Mr. MINETA. When you say you have research funding as soon as the technology is in place, but you need the funding in order to do the research?

Dr. LENOIR. We have requested the funding, it is just not in my budget. It is in Arnie Aldrich's Aeronautics, Exploration and Technology budget to do that research. That would primarily be done through Ames, being one of the Aeronautics Exploration and Technology centers.

But I have not, in the Office of Space Flight, other than the fiscal year 1991 line under exploration, requested money specifically for suits. Our suit money in 1991 is tied up with exploration, and the Office of Aeronautics, Exploration and Technology has requested some general funding for research into high pressure suits. We have coordinated our plans. We do not have two different plans.

Mr. MINETA. Roughly how much is in Arnie's budget for that purpose?

Mr. KOHRS. I think it is probably around $9 million to $17 million, I'm not exactly sure.

Dr. LENOIR. I believe it is $17 million. We can find out.

Mr. MINETA. And how long will it take for you to comply with what the committee is requesting? Is there, within this fiscal year, an answer you would be coming back with, or is this going to be continuing?

Dr. LENOIR. The request for the data of such an evaluation can certainly be within the fiscal year 1991.

Mr. MINETA. Dr. Kerrebrock, I was wondering if you would expand on your fourth conclusion in your testimony that your subcommittee had the impression that there was a lack of coordina-

tion between the several groups developing tele- operators at Level 2?

Dr. KERREBROCK. Let me just say that the plans for utilization of tele-operation in the assembly and maintenance of space stations are preliminary, they are really in the process of formulation. Until just quite recently, for example, there were no specific tasks assigned to the FTS, the Flight Tele-Robotic Servicer. The R&D on the FTS was launched as sort of a parallel effort with the space station, as I understand it, as a generic tele-operation device which would be useful in space station operations, but without specific task assignments.

I think the situation is probably analogous to the Canadian manipulator, the SPDM, although we have less information on that. But the absence of firm requirements or tasks for these devices has resulted in a situation where the people designing the FTS, developing the technology, had to make it more generic, perhaps, than they would have if they were more closely coordinated with the people designing the things that were to be assembled.

Now I must say this is being fixed. If I understand correctly, Mr. Kohrs either has or is in the process of establishing a single point of responsibility at Level 2 to coordinate these things. I think that coordination will improve in the future.

Mr. MINETA. Dr. Kerrebrock, also in your testimony you referred to the estimated cost for developing and procuring an advanced high pressure EMU at $200 million to $400 million. You also mentioned that the suit is suitable for full-scale development, and close to pure design. Would you explain this further, because until now I was under the impression that the advanced suit was in preliminary design, that it was not suitable for full-scale development, and would closer to that $400 million level. Would you explain how your committee came to these conclusions?

Dr. KERREBROCK. Yes, sir, there are several points there.

First, to clarify the question of cost, it has been pointed out here that the hard estimate is some $300 million. I think Mr. Kohrs answered that question a little earlier. My subcommittee agrees and I agree with Dr. Lenoir's point that an advanced high pressure suit which is developed should synthesize the best features of the Johnson Mark 3 and the Ames AX5, take the best features of all of those and include them in the final design.

The difference between the prototype suits which we have now, which are working pieces of hardware—people can get into them, they can jump around and demonstrate the suits, even operate them under water to perform tasks and so on— the difference between the prototypes and fully developed hardware, which is suitable for production, is a matter of refinement of the designs so they incorporate all of the things we have learned and are as appropriate as possible for serial production. That's what we mean by full-scale development.

I would like to emphasize that the EMU really consist of two parts. One is the suit itself, the other is the portable life support system. The portable life support system is by far the most expensive component of the two. There are opportunities for reducing the consumables requirement from the values for the present shuttle suit through the development of a portable life support system

that does not, for example, use lithium hydroxide to remove the CO2.

Mr. MINETA. Is the present life support system adaptable to use with the advanced support system, or would that require a totally new design requirement there?

Dr. KERREBROCK. If we want the EMU to be station based, that probably implies the desirability of reducing the consumables requirements, for example, the lithium hydroxide. There is technology available called variously molecular sieve or absorption/desorption technology, whereby the CO2 can be removed from the gas in the suit, without using a consumable like lithium hydroxide.

That technology, as I understand it, is probably going to be incorporated into the station itself. It is available, there is no question about that, except for the cost of developing the portable life support system.

In the view of my subcommittee it would be desirable to incorporate that kind of change along with the high pressure suit in a second generation or advanced EMU. That is included in this cost figure, though, that I quoted, of $352 million, is that correct, Dick?

Mr. KOHRS. Yes, $352 million.

Mr. MINETA. Dr. Lenoir, how do you react to the kinds of conclusions that Dr. Kerrebrock talked about? Some of it, it seems to me, please correct me if I am wrong, seems to be in contradiction to what we have heard in the past.

Dr. LENOIR. I don't think so. When I hear what Professor Kerrebrock says, if I listen carefully to the words, I am in agreement. The idea that each of these suits, the Mark 3 and the AX5, is essentially—or almost whatever adverb we wish to put in there—ready to be developed, is an engineering statement in my mind.

That does not imply that that particular design is fully operationally acceptable. That's where we have to say we have to get our users, our crew, involved. There are some shortcomings of each. Actually each one has a considerable number of shortcomings, but if I allow myself to pick and choose one over the other, I only come up with two areas we feel are still short.

Now, we have never built that composite suit to see if indeed they work together. That's why we say from an operational point of view, more development is required. We are not ready to go build the suit in an engineering sense. We could, but operationally it would not be as effective as we would like it to be. Therefore, we think we have more technology work to do to make it good enough to really be our next generation suit.

Mr. MINETA. And the $352 million includes the life support system, or is that in addition?

Dr. LENOIR. That is in it.

Mr. MINETA. What is the breakout between the two?

Mr. KOHRS. Between the backpack and the suit—about 75 percent for the backpack, and 25 percent for the suit. And that number is $342 million, I just looked it up. It's an answer we sent back from a May hearing we had. It is $342.5 million, and the split was about 75/25.

Mr. MINETA. Thank you very much. I yield back.

Mr. RHODES. With this—at least to me—incredible number of hours that you need for external maintenance of the station, that

implies that there is an awful lot of stuff out there that is going to be broken and having to be replaced, and that implies spare parts, which implies logistics. What's the status of an operational logistics plan, for spare parts, for storage of spare parts, transportation of parts, repair of damaged parts, etc.?

Dr. LENOIR. Well, you asked earlier about our operations costs. That was a major part of our study, to build up our logistics thinking and put together what we would call an integrated logistics support plan as part of that. Now, we do not have that plan completed, but we have estimated what that involves. That is a major fraction of the total operations cost, to support the logistics program.

We have learned a lot in the space shuttle program about our logistics support. Some of what we have learned there will be applicable here. Of course, we have an added complexity here in that the thing we need to maintain is in orbit, not in an orbit processing facility. A major focus of our operations effort this coming year is going to be to put more meat on our logistics planning bones.

Mr. RHODES. Is there space in the station for a reasonable supply of spare parts?

Dr. LENOIR. We think so. The nodes, which are almost like half module sized things that connect the individual elements together, were invented to house external equipment that we would not put outside, but would put inside instead, and to be somewhat like a warehouse for storage.

Mr. RHODES. Can you define for me what the term "ship and shoot" means?

Dr. LENOIR. "Ship and shoot" is a term that we use early in most of the programs that we deal with, and wind up not doing. "Ship and shoot" means essentially that whoever builds it or wherever the hardware is manufactured and tested, that they fully test it there, then bundle it up and ship it by airplane, truck or whatever, to the Cape, and all the Cape people is do is take it out, bolt it to the space shuttle, and fire it into orbit.

At various times in this program, this has been our concept. Because of digging into the verification planning and requirements for deeply making sure that whatever humble lessons there are to learn, we learn them. That is not our current concept. We have not worked out the depth of details we need for our KSC based verification efforts, but they will not be zero. That's essentially what "ship and shoot" is.

Mr. RHODES. And there will be KSC verification?

Dr. LENOIR. Yes.

Mr. RHODES. Is pinning down that plan another part of the PDR process?

Dr. LENOIR. That will be coming primarily out of the PDR. That will be part of our verification planning effort that will be one of our major objectives in fiscal year 1991.

Mr. RHODES. Thank you, Mr. Chairman.

Mr. NELSON. As a follow up to one of your questions on spare parts, your response to Mr. Rhodes on spare parts was talking about the nodes, you are actually talking about systems that are in the nodes, not a place for the storage of spare parts.

Dr. LENOIR. I meant both. We will have systems that are mounted and operating in the nodes, but also that is a convenient locker, if you like, to store hardware that is just spare parts until you need it.

Mr. NELSON. Does that get to your question?

Mr. RHODES. Yes.

Dr. LENOIR. And also as Dick points out, also in the logistics module, which is the carrier that brings them up.

Mr. NELSON. Let me say if I can start tying this all together. Mr. Mineta, Mr. Rhodes, leap in anytime you like. I am going to go through a series of questions here.

You have indicated that you know how to fix the EVA and external maintenance problems. Have you include funds in the fiscal year 1992 planning for the 1992 budget to carry out the required fixes?

Dr. LENOIR. Yes, we believe we have.

Mr. NELSON. How much?

Mr. KOHRS. The EVA fixes, which would take you from the 3,000 hours down to 1,100 hours, the estimate we have had is about $20 million total over a six-year time frame, well within my capability of reserves that I handle. The robotic fixes, which get more costly, if you get more detailed, we will deal with those on an item by item basis, and make a decision whether it is robotic or EVA maintainable.

Those will be done to balance the budget, to balance the schedule. But I think it is within my budget that we have submitted.

Mr. NELSON. Is that $20 million a year?

Mr. KOHRS. No, total, over about six years. So it is $2 million or $3 million a year.

The EVA fixes, if you recall the Fisher-Price and the Center report, most of the EVA fixes are buying duplicates of what we have already developed. We are building a crew translation aid that flies down the middle of the truss. The recommendation is to have two of them, so we can have one astronaut go one way, and one go the other way. Additional handholds, additional footholds, additional tethers, most of those were not development items. We are buying more of the same. Additional tools—we could have two sets of tools versus one set, that type of thing.

Mr. NELSON. That's $20 million total. How about funds in 1992 for robotics fixes?

Mr. KOHRS. I think within my what I call reserve posture I have enough funds to do that tradeoff to provide the funds necessary for robotics fixes.

Dr. LENOIR. We have identified what we call liens against Dick's reserves. We have a potential for spending $50 million in this area, therefore we chalked it up and said that's a lien against his reserves. We don't know exactly how that is played out, whether it is $45 million or $55 million or whatever. But that does allow us to do some financial planning.

Mr. NELSON. Is that known as budgetary blue smoke and mirrors?

Dr. LENOIR. No, we don't believe so, because those reserves are in his requested budget.

Mr. NELSON. Does that mean the answer to the question is no funds allocated in 1992 for robotics?

Mr. KOHRS. There are funds allocated. There are no additional funds required.

Dr. LENOIR. What that means is that as we look at the out-years, we request a certain reserve. As those years get closer to us, then in subsequent year budget subheads, we allocate some of that reserve against the things as we get smarter. That's what we have done, is to take 1992 reserves that were proposed in 1992 last year, and in this year's budget we allocated them against various fixes such as robotics.

Mr. NELSON. How much are the reserves in 1992?

Mr. KOHRS. It is approaching $300 million. I guess it is $279 million, if I remember. My mind is totally blank.

Mr. NELSON. And in that reserve, that would be for contingencies, reserves for everything?

Mr. KOHRS. For some of the other things we have talked about, like verification that we may have to do some other funding. We think now our weight and power fixes are budget neutral, if you will. Some have costs, some save. That may not quite come out that way, so we have, like Dr. Lenoir said, a liens list that we keep in front of us that we deal with on a day to day basis.

Mr. NELSON. Is that about a 12 percent reserve?

Mr. KOHRS. More like 10 percent.

Mr. NELSON. Is that prudent planning for reserves?

Dr. LENOIR. Well, of course, we would always like more, and if offered more, we would accept it. But we believe for the reality of the situation, the likelihood of the budget that we will actually get in 1991, and that if we did run into significant problems that required more money, it probably also will require more time, and that is probably about what we can intelligently spend in that year, whether we are totally successful or have a few problems.

So I think yes, that is prudent.

Mr. KOHRS. To give you a benchmark, in 1991 I have roughly spent $175 million of my reserves that were allocated, excuse me—1990.

Mr. NELSON. Out of how much?

Mr. KOHRS. The 1990 budget was—

Dr. LENOIR. What was the reserve you started with?

Mr. KOHRS. It was $204 million.

Mr. NELSON. You spent $191 million out of $204 million?

Mr. KOHRS. About $100 million. Close to that. And the 1990 budget is $1.74 million.

Mr. NELSON. Let me go back to the Fisher-Price study. It said four EVAs per week from the shuttle will be required before the station is permanently manned. That was based on 6,300 hours of EVA. Do you agree with that Fisher-Price finding?

Dr. LENOIR. I agree that that is their finding. That is the equivalent—

Mr. NELSON. Do you agree with their finding?

Dr. LENOIR. No, I can't agree, given where we are today. We have not stood still. Given the constraints and the assumptions they made, I probably would have come to the same conclusion. I am not throwing stones at their conclusion. For where they were,

and what they look at, yes, that's the reasonable assertion. That's the same as the five EVAs per week in the operations phase that we think we now have down to one EVA every eight to ten days.

Our efforts in the assembly arena are lagging about three or four months behind the operational era, and we intend, as Dick has pointed out in several reports we have sent, to use the same process. Whatever EVA efficiencies we gather in solving operations, those will be directly applicable in the assembly phase as well. The robotics may or may not, and of course, the hardware may or may not.

Another thing we have to look at in assembly, though, is Fisher-Price assumed that every piece of equipment that was brought up and you immediately started using it up. We may find, based on some of their analyses, that we launched some equipment earlier than we needed to. If we have to worry about it failing shortly after that, I will launch it later, then it becomes less of a problem. Or I may launch it, but not turn it on if I really don't need it.

So I have a few more tools in my tool kit in assembly than I have in the total operational area. But on the other hand, I am a lot less flexible operationally. So I really do need a few more tools.

Mr. NELSON. You said that you expect a lot less EVA, because of the changes in the assembly. What are the changes?

Dr. LENOIR. We mentioned in the weight and power that we have eliminated a fair number of orbit replaceable units. If they are not there, they do not ever need to be maintained. When we re-do the assembly sequence following the preliminary design review, we now have a very strong focus on external maintenance, EVA and so on, that we did not have when we built our current sequence. We will be asking ourselves, not only from a structural point of view, but if that is the right order of doing things from a maintenance point of view.

Mr. NELSON. Will you provide the committee with a list of the changes in the weight and power structure?

Dr. LENOIR. Sure.

Mr. NELSON. What will be the cost impact of your new strategy on the assembly phase maintenance EVA requirements?

Dr. LENOIR. We don't know yet, because we have not fully worked it out. I believe we will be able to accommodate it within our current budget, but I can't prove that yet.

Mr. NELSON. Dr. Kerrebrock, do you want to comment on this subject?

Dr. KERREBROCK. On the cost?

Mr. NELSON. No, on the overall EVAs required, the reduction of weight and power to cut down on EVAs during assembly.

Dr. KERREBROCK. No, I think the only thing I would be able to say would essentially be a repetition of what I said before. First of all, let me summarize that very quickly. The estimates of the requirements for maintenance are still tentative. There is a fundamental uncertainty, then, in all of these things.

The progress that has been made by the external maintenance task team in reducing the estimates has been in a projected improvements procedures for maintenance, such as having two-seated carts, as Dr. Lenoir said, and other things like that. That changes

the estimate of what they call the overhead time, the preparation, disassembly time, and so on.

That's a multiplier, if you like, or an addition to the basic time that is required for the actual repair task. There is a factor of three there, and there is another factor of two, a gain which is projected to take place by using tele- operation instead of EVA. Altogether there is a factor of six, projected reduction in the EVA requirements relative to the initial estimate.

The initial estimate still contains the fundamental uncertainty that we don't know exactly how often the devices will break, and we don't know exactly how long it will take to repair them when they do break.

Given that fundamental uncertainty, there is a residual doubt as to whether we will be able to do it in the available time. But I think there is nothing that can be done about that at this point, other than continue the refinement as preliminary design review goes on, of the understanding of the devices themselves and their likely reliability.

Mr. NELSON. All right, you are talking about mature operations. We are talking about assembly.

Dr. KERREBROCK. I'm talking about both.

Mr. NELSON. About both. All right.

Mr. Kohrs, you indicated last spring in a hearing you had with Captain Walker—how much EVA did the Walker team estimate would be required to assemble the Phase 1 space station?

Mr. KOHRS. We are working on a ground rule that says for every shuttle flight, build your plans that there is 24 hours per shuttle flight. The capability per shuttle flight is 48 hours. Twenty-four hours is two two-people EVAs, and 48 hours is four-people EVAs. In the PDR process, I put a ground rule in that says you cannot exceed 24 hours until we get through preliminary design. Once we understand preliminary design, I will let that group use up to 36 hours, which would be three EVAs for two people. Then this program will hold back 12 for contingencies.

So the assembly sequence, when we talked about doing it in 28 missions, or 18 plus 10 logistics: is based on that set of ground rules. Captain Walker will tell you that on certain flights he is busting the 24 hours today, and he is up to maybe 32 or 36. But knowing that we have this program reserve, until we better understand the design, and better understand how we assemble this thing, I am optimistic we will be able to live within the 36, and then with the 12 hours contingency.

Dr. LENOIR. And some flights are under, that don't take the 24, that is of course the trade, do we spend the reserve to get it up higher, or do we move that activity to a different flight that has more time?

Mr. MINETA. Will you yield on that? How long do you expect that PDR to stretch out?

Mr. KOHRS. The subsystem PDRs and the work package PDRs have been going on all year. We have had over 80 of them at different levels. The systems integrated PDR is all of November and the board is the 17th of December.

Dr. LENOIR. Let me add to that. That assumes that the fiscal year 1991 budget we have requested is actually what is appropriated.

Mr. KOHRS. Yes.

Dr. LENOIR. Frankly, with the numbers we are looking at, I am worried that we may not be able to effectively complete the entire PDR in fiscal year 1991, because of the efficiencies and the slow start we will get if the first thing we will do as we get into October is to downsize our contractor work force. We will have difficulty making sure we get through the PDR within the fiscal year 1991 time frame, not just December.

Mr. MINETA. How do you slip from December to not within the fiscal year? Do you have any ranges as to how much less than how much you have requested that comes in that has that kind of an impact?

Dr. LENOIR. I really don't, Mr. Mineta. If we had the worst cut of what we are looking at, my preliminary thinking is that my goal for fiscal year 1991 is probably going to be to complete the PDR process. We will want to complete this PDR even though we know some of the areas will change drastically, due to the decreased budget.

But as I mentioned earlier, we have lost our momentum because of the uncertainty of starting the fiscal year. We have already lost momentum. We have had to send out messages to our contractors to stop growing as they had planned. So we have slowed it down. Even if Monday, the first of the fiscal year, the tooth fairy came in and gave us our entire budget request for the year, we would have lost some momentum, and probably by the time we finished replanning and rephasing, we would find we were going to have to slip out of December for the completion.

I don't mean to sound like the sky is going to fall and there is no way we will get PDR done in 1991. I honestly think that with a reasonable budget compromise, we will probably sometime after the first of the year, not by December but by no means out of the fiscal year.

Mr. MINETA. I thank the Chairman.

Mr. NELSON. Mr. Kohrs, I had asked you about the Walker findings. You started telling me about the ground rules. Then you said Captain Walker would insist it was more than 24 hours. What are the Walker findings?

Mr. KOHRS. Dave Walker runs a review for the program called the Assembly Planning Meeting, where he gets representatives from the whole program, all the projects, all the contractors in Level 2, and pulls together the details of how you put the vehicle together over these phases. Dave does the planning for Flight 1 and Flight 2, and he has to put truss work together for the center.

He says for this particular configuration it may take 36 or 38 hours in our current assembly sequence. He will come to the program and say "I am busting your ground rule of 24 hours." We say "Press ahead, because we are going to look at this thing as part of the PDR process." My plan was, if we had this well understood, to come out of the PDR process I would up the 24 hours per mission to 36 hours. We are just that more mature in the program.

We are synced up as to how we are working this. Now if he comes up and says it takes 52 hours of EVA, we will have to redo the assembly sequence. This is on a mission by mission basis. Like Dr. Lenoir said, some missions where you bring up a lab module that is fully outfitted and takes up all the shuttle performance, there is hardly any EVAs on those missions, because you are devoting the whole time to installing the lab.

Dr. LENOIR. Where Dave has found shortfalls are in individual maintenance, but looking over the entire ensemble of assembly flights, his estimated total requirement does not exceed our total availability.

Mr. NELSON. May we have a copy of that Walker report?

Dr. LENOIR. It is not documented. We will have to document it for you.

Mr. KOHRS. What we do is put out periodic data dumps to the staff, so we will provide the latest ones to you.

Mr. NELSON. Whatever Walker reported to you, may we have a copy of it?

All right, now let's talk about internal maintenance. We have been talking about external maintenance.

What are the current estimates for internal maintenance, both in the assembly phase and in the operational phase?

Dr. LENOIR. I will have to defer to Mr. Kohrs here for the numbers, but basically let me remind us all that our concept for operating the space station facility is that when we are operational we have eight crewmen on board. Two are dedicated to operating and maintaining the facility. The other six are dedicated to operating and performing the experiments and utilization activities.

So when we talk in terms of two shifts, each shift of four people, each working 12 hours, then at any given time there is one person dedicated to the facility. It is out of that total that comes both the EVA maintenance and the internal, the IVA maintenance, as well as the operations of the facility.

The facility ought to almost operate itself. Therefore most of that allocation is available for internal maintenance. I don't know whether we have a definitive number we can give you off the top of our heads today for internal maintenance, or take action to provide it later.

Mr. KOHRS. We don't have that available.

Mr. NELSON. Dr. Kerrebrock, did your people look at internal maintenance requirements?

A national research council committee in 1988 said that "Current schedule for the on-orbit assembly of the space station appears incompatible with the integration and verification requirements." Since that 1988 report, the schedule has shifted. But the spacing between the assembly flights does not appear to have changed significantly.

Now how do you accommodate on-orbit assembly or verification problems in the assembly sequence that appears to have little or no slack?

Dr. LENOIR. We are also worried about that very issue. That is what is driving our concentration on our verification planning and the development of a detailed verification plan in the upcoming fiscal year. We believe that since then we have relaxed the assem-

bly sequence slightly, not a lot, but slightly. As we look at it on a flight-by-flight basis, we believe we have enough time to do that in a reasonable sense. We must prove that this coming year with our verification plan.

Mr. NELSON. What historically has been the amount of time required to verify a spacecraft on orbit?

Dr. LENOIR. We don't have a historical counterpart of a spacecraft like this that has grown step by step. If you look at a communications satellite that you launch, of course there are no people there, it can take you typically two or three months to feel you have totally verified it and checked it out.

Similarly, on our systems, it took us—if I take the shuttle remote manipulator system —it took us many flights to complete the verification of that, because that was not our primary reason for doing it. And when we had time available we tried it with this weight, that weight, and so on.

I don't think there is a very good counterpart to compare that to, where we have over a long period of time built, in a stage sense an increasingly complex facility.

Mr. NELSON. How much time are you allowing between assembly flights?

Dr. LENOIR. Essentially most of it, and during it. We will be doing some real time verification right then and there that you will want to make sure something has or has not happened before the crew leaves. And the time in-between can be spent from ground based control to a fairly rigorous check- out of the systems involved.

Mr. NELSON. On your plan, how many days and months between your different assembly flights?

Mr. KOHRS. The first two years we have five flights a year. That is roughly 70 days between flights, and two years of eight flights a year. Those are not all assembly flights. Some of those are logistics flights. Eight flights a year is 40 something.

Dr. LENOIR. We have said no more than five assembly flights in a year. For the first two years 70 days liftoff to liftoff.

Mr. NELSON. Seventy days—how does that compare to your historical experience in check-out of the spacecraft, even though, as you have said, they are not comparable?

Dr. LENOIR. We believe that when we look at a comparison of a communications satellite, like a communications satellite, add in how we verified the space shuttle in an environmental sense and in a systems operation sense, we believe that is reasonably compatible. A typical check-out for a very complex communications satellite is 60 days. That has reserve built into it. That means that somebody has committed that in 60 days it will be fully operational or he is going to start losing money.

Mr. NELSON. Dr. Kerrebrock, did your committee look into this question?

Dr. KERREBROCK. No.

Mr. NELSON. All right. Let's talk about the unpleasant reality of cuts that are really as we speak probably being decided—assuming they are reaching any decisions—that the summit committee has reached that resumed at 12:00 o'clock today. What options does the

space station program, and are you considering to deal with these potential cuts?

Dr. LENOIR. Let me preface that by saying that we do not have a plan that says, at this level here's what it looks like. What we have are some things to look at, none of which have we finished looking at. I think in some cases we will find that something we proposed to do does not actually save us any money.

It is difficult to save money in the fiscal year that is right upon us. That's the real nature of our problem. We wind up doing it very inefficiently by cutting our work force back, hanging on to most of our content, and taking what happens with the schedule. That's what we are trying to avoid. I don't think we will totally succeed.

We are looking at things like anything that is outside, does it have to be here? Our first choice is, what if I eliminate it? Who's the first person that's going to scream? That we look at as a simplification that also solves weight and power problems, and so on.

Our environmental control system, as you know, both the air and the water loops are closed. One option is to suspend work on those systems effective today, push them downstream and for whatever period of time, operate open loop by taking consumables, primarily oxygen and water, up. It is less efficient, but involves less money in fiscal year 1991 and 1992.

Smaller elements, modules, nodes, etc., that would be less expensive to develop and build, and incidentally easier to launch—help me Dick, I think there are some other things. And as I mentioned earlier, solar dynamics and any other the other things that we think are nice to do but we need to get a leg up on for the future, if the basic space station is threatened, I have to take those future activities and say they are less priority.

Mr. NELSON. At what point do you recommend termination of the program?

Dr. LENOIR. When one of two things happens, I think, and that is either the resulting space program we can put together does not meet the requirements well enough to be worth doing, or another one I feel internally I want to get through is if going through the coming fiscal year represents no forward motion, just to spend money to stand still does not sound like what the country ought to do.

One of the big questions we have is, if we have a serious significant cut, what should we assume about fiscal year 1992 and fiscal year 1993? It is probably not realistic to assume a step increase that gets us back to that budget. That's what really drives us in our thinking for what we can do and in what order we can do it. More than just the 1991 cut is what does that bode for 1992 and 1993 and 1994?

Even if it is a much smaller level, if I can achieve the stability of knowing what it is and actually receiving it every year, we can design a program that is a lesser space station, but we can deliver. It will meet some subset of the requirements.

Mr. NELSON. Do you have any of those descoped design options under study?

Dr. LENOIR. We have some of those descoped options under what I would call definition, trying to figure out what they might be. We

don't have them under study yet, because we have not defined what the options are.

Mr. NELSON. If I were in your shoes I would answer that question just like you did. My compliments.

If after the PDR you face significant funding uncertainty, what will be your recommendation that should be taken in the space station? You have done PDR, then you are looking at funding uncertainties.

Dr. LENOIR. Frankly, after PDR we are in a better position to take budget cuts than before, because then we have a well-defined and well-documented baseline that I can work away from. It would be easier to look at incremental changes to removing this hardware, deleting this requirement and so on, than it is today.

As I mentioned earlier, our number one priority for fiscal year 1991 must be to complete this PDR so I have a well-documented concept that if I cannot afford, at least I know what it costs and what it looks like. Then I can subtract away from that to get to what I can afford.

Mr. NELSON. Here's the thing I want to you deal with, the realities of the budget. We want you moving in the direction of considering contingent plans to deal with funding shortages.

Dr. LENOIR. We are.

Mr. NELSON. Mr. Browder?

Mr. BROWDER. Thank you, Mr. Chairman.

I don't have ary questions. I would like to express my appreciation to you and the staff for this hearing and for our people who have come before us today. I do understand it has been a productive meeting, and for that I commend you.

I would like to explain that we had a closed Armed Services meeting and a meeting with the Speaker about the budget negotiations, so I apologize for not having been here. But as I said, I understand it has been a very productive session.

Mr. NELSON. If you had a meeting with the Speaker about the budget negotiations, would you share that with us?

Mr. BROWDER. Well, this was a meeting where I listened, rather than where I negotiated.

Mr. NELSON. I take it this was prior to his going into the meeting at 12:00 o'clock?

Mr. BROWDER. Actually our meeting went past 12:00 o'clock.

Mr. NELSON. Well, then, something has changed. I thought they were going to go back into the summit.

Mr. BROWDER. It may be that he is still going into it, because we just broke up there. I left just in time to walk over here, and he was still talking to a few members. But you know how meetings go. His 12:00 o'clock meeting may still be scheduled.

Mr. NELSON. Let me ask you, Dr. Lenoir, in the House Appropriations Bill there is a $750 million cap on spending. How does that impact the space station program?

Dr. LENOIR. If we were to get our full budget request, or even as cut, and it came in a timely sense, which it already has not, then it should have no effect other than a loss of flexibility. But if we looked at the rate at which we would spend it and when we would get it, I assume that their constraints we are doing anyway.

So the issue has to be how do we prove we are doing them? Telling them is not enough. The results of PDR would have to be that proof. If we had a little bit of a delay, as we already have had in starting, and therefore finishing the PDR, that is a loss of flexibility which is going to make us even less efficient, because we don't have the money to finish it. We don't take issue with the commitments we have already made, and still intend to do, if we can afford it. It is the lack of flexibility that gives to us.

Mr. NELSON. You will recall that earlier this year you and I had a difference with regard to a heavy lift vehicle, funding for the shuttle. We put that in a subcommittee markup. When we did the full committee markup, I took that out, save for the $10 million for research for a heavy lift vehicle. I did that because of the budgetary constraints. But I also did that because of your assurance earlier in the year that we could assemble the space station by using just the space shuttle.

I am not totally convinced, but would you give us assurances right now for the record?

Dr. LENOIR. Yes. For the record, we are convinced we can assemble the space station using only the shuttle, and that our challenge is to step forward and prove that to you by doing it.

Thank you.

Mr. NELSON. Dr. Kerrebrock, in the Fisher-Price team's results, it appears that a significant amount of total crew time will be spent maintaining the station, rather than performing experiments. NASA's solution relies heavily on the use of the tele-operated robots. Yet in your testimony you state, "While space station robots may reduce the demand for EVA, they are not likely to significantly reduce the demand on crew time."

What do you think about NASA's proposed solution to the EVA problem? Will it solve these underlying problems such as the total amount of scarce crew time?

Dr. KERREBROCK. Well, I believe the estimates that are being made of the required crew time are about as good as can be made given the level of certainty of the basic data. Whether half of the actual tasks can be offloaded to tele- operators or not I think will remain a question until we are through PDR and we understand exactly what the designs of each of the ORUs is, and what the strategy for maintaining it, repairing it, replacing it with a tele-operator is, and furthermore, after those tele-operators have been designed for that purpose.

There is a level of uncertainty there, which I believe you can see has made my subcommittee nervous about the prospect. It is that uncertainty which has led us to suggest development of the advanced suit which would make available more productive EVA time to respond to any difficulties that arise, as a result of those uncertainties.

Dr. LENOIR. Could I amplify that? Our intent in removing EVA wherever possible, and if you like, turning it into an IVA operation by tele-operation. is to recognize that we have available somewhere between five and ten times as much manhours in an IVA status as we have in an EVA status. So if the total length of time is fixed, there is a much bigger reservoir of IVA hours than there are EVA

hours. So we think that is a good trade, and obviously it is less risky.

The other thing we have not talked about as we have dealt with money for additional suits, is another way I could spend some additional money, to incorporate a radio frequency link and to do my tele-operations with a crewman on the ground. These are all trades that must be made that have not yet been made.

Dr. KERREBROCK. Could I add to what Dr. Lenoir has said?

I agree with his comment. The extra reservoir of time he is talking about, I think, is the time when the crew is on the station when the shuttle is not docked at the station. A station based suit would make EVA available during that same reservoir of time.

Mr. NELSON. And that is a good point. And I thank you. He certainly agrees with you, it is a question of dollars.

Dr. KERREBROCK. That's right.

Mr. NELSON. I want to ask you again about shuttle assembly flight. Is it realistic that the assembly sequence, requiring up to eight flights a year, when in fact post-Challenger—not post-Challenger—when you take out the down time from Challenger, the average at most has been six flights a year since operation?

Dr. LENOIR. We think it is, and for the following reasons. On the shuttle side of our house, our challenge in the next two years is to instigate a plan and to demonstrate a reliable supply of shuttle missions of about 10 to 12 per year, and if by the time we get to the first station assembly flight, we should have been operating in that mode for three or four years to demonstrate that indeed that is the case.

Now when we say eight flights a year, I look on that as four or five assembly flights. Those are different. The logistics flights or utilization flights that happen in between those are different operationally. They require the space shuttle, but they are easier to postpone and move around. We believe that we are well on the way toward a reliable 10 to 12 flights per year with our shuttle system as we have it, and it will have been demonstrated for several years by the time we enter the station assembly.

Mr. NELSON. I might say that I agree with the reliance on the space station. I just want to keep poking and prodding you toward other than the budgetary considerations, which are very real, that you need to be continuing to look at the heavy lift capabilities that complement your ability. You need to look at supply modules that don't have to come up in the space shuttle. And of necessity, you must look to a crew rescue vehicle that would be attached.

I would also encourage you, Dr. Lenoir, that with the beginning of the flaw discovered in the Hubble telescope, that NASA has had a considerable public relations problem. It seems that when it rains, it pours. You should consider the public relations image question, not just the technical question, when you approach these questions of where you might have a hydrogen leak in the future, or something akin to a hydrogen leak, or whatever. That is a normal problem in an R&D program.

But you have the world looking over your shoulder. Technically you may be correct in making a decision, for example, not to tank and do a tanking test. But had you done it, you would have spared the embarrassment of going through a countdown only to discover

another hydrogen leak. So I want you to put that into your equations as you consider future activities.

We are down to just a few minutes, so we are going to have to bolt out of here.

Mr. Browder, what's the vote we have going on? We are down to about five minutes, so I think we are just going to go ahead and adjourn the hearing.

Let me tell you, it has been quite elucidating. We wish you the best. We are looking forward to your success, and we will continue to see you in the hearings as other subjects come up.

Dr. LENOIR. We thank you for your support.

Mr. NELSON. Thank you. The hearing is adjourned.

[Whereupon, at 12:49 p.m., the subcommittee was adjourned, to reconvene at the call of the Chair.]

[Additional material submitted for the record follows:]

Responses to written questions submitted by Chrm. Nelson resulting from the September 27, 1990, hearing.

QUESTION 1:

The Space Station program has reserves included in its funding requests:

a. What reserves are included in your FY 1991 budget, and what are the current and planned liens on those reserves (by category)?

b. Will reserves be used in FY 1991 for EVA fixes and Robotic fixes? If so, what amount do you anticipate allocating to each category? For what purposes?

c. Please answer (a) and (b) for FY 1992.

ANSWER 1a:

There is approximately $350 million in reserves included in our FY 1991 budget request. Liens currently total $440 million covering such items as lab support equipment, new or expanded facilities for Space Station integration and verification, closing the environmental control and life support system at permanently manned capability, preliminary design review item discrepancies, the Flight Telerobotic Servicer (FTS) development test flight number two simulation, systems engineering/ integration, and several others. Liens will be prioritized and funded only to the extent that funding is available and the scope is consistent with program objectives.

b. A portion of the FY 1991 reserves will be used for preparations leading to an assembly flight demonstration in a later year, flight experiments with varying EVA and robotics related objectives, studies to determine Orbital Replacement Unit (ORU) compatibilities with robotics concepts and activities related to potential FTS applications not in the current baseline. While the precise scope of these activities is not yet known, it is estimated that as much as $50 million of the FY 1991 reserves could be applied to these and other areas involving EVA and robotics.

c. We are currently formulating our FY 1992 budget request which will include reserves. As you know, we cannot provide that data until the budget request has been finalized and submitted by the President.

QUESTION 2:

Dr. Lenoir indicated at the September 27th hearing that the program might not be able to complete the PDR during FY 1991

a. How soon after you receive you final appropriation level will you make a decision on when to hold the PDR?

b. If you do delay completion of the PDR, will you also delay initiation of the program-level PDR or will you extend the duration of the program-level PDR? Why?

c. If the appropriation is low enough to require major architectural changes, will you still conduct a PDR on the current design? Why or why not?

ANSWER 2a:

We still plan to complete the integrated system Preliminary Design Review (PDR) before the end of this year.

b. The scheduled Work Package PDR's have been completed; we initiated the program-level PDR on schedule on November 12.

c. Yes. We feel it is important to establish a firm baseline from which to make any changes necessitated by FY 1991 budget reductions. The program level PDR will bring together the results of the Work Package PDR's and of the weight and power Turbo Team activities, culminating in a single baseline to which the changes from the budget reduction will be made.

QUESTION 3:

At the September 27th hearing, Dr. Lenoir gave the operations concept for internal maintenance requirements on the Space Station. In July it was indicated to staff that the Space Station program had a team attempting to quantify internal maintenance requirements, and that the team would be coming up with the estimates by the early fall:

a. What are the current estimates of the internal maintenance required on the Phase 1 Space Station in crew hours per year (at Assembly Complete and during the assembly phase)? On what are those estimates based?

b. Do the internal maintenance estimates include the international modules?

ANSWER 3a:

Last summer, we initiated a several month activity to determine estimates for internal maintenance requirements on the Space Station. The analysis is largely dependent upon the outcome of the integrated system preliminary design review. We will have current estimates sometime after its completion.

b. Yes, they will.

QUESTION 4:

What do you consider to be an acceptable level of maintenance and repair EVA prior to Permanently Manned Capability (PMC)? On what do you base your answer, and do you plan to baseline that level at PDR?

ANSWER 4:

Determination of the acceptable level of EVA for maintenance and repair prior to PMC will be one outcome of the integrated system Preliminary Design. As we said before, we believe we will emerge from PDR with acceptable levels.

QUESTION 5:

Will any new or expanded facilities be required for Space Station integration and verification? If so, how much do you estimate they will cost? Are they included in your current program budget estimates?

ANSWER 5:

One major focus of our FY 1991 activities will be the baseline of an integration and verification plan. During the summer of 1990, the Space Station Freedom Program conducted a review of integration and verification requirements, with the goal of strengthening these functions to enhance the safety, reliability, and durability of the Space Station. This review resulted in the identification of several expanded verification requirement options. These options are still being assessed by the program; if implemented they could require additional facilities. New facilities for these requirements were not included in the FY-1991 budget submitted to Congress in January, 1990. R&D expenditures will be handled through reserves.

Material requested for the record on page 71, line 1668, by Cong. Mineta during the September 27, 1990, hearing.

The Office of Aeronautics, Exploration and Technology (OAET) supports research and technology efforts for high pressure suits within two of its programs. In the Space R&T Base program, the objective is to conduct research for EVA systems which are rugged, highly reliable, mobile, and readily serviced. The scope of the effort includes suit concepts, dexterous gloves, and information management and displays.

The proposed FY 1991 activity under the Exploration Technology program is a focused effort to develop and demonstrate the technology required for a surface suit for lunar and Martian missions. The extravehicular activity systems needed for the Space Exploration Initiative have unique requirements, such as dust countermeasures, low suit weight under 1/6 and 1/3 gravity conditions, and mobility over rough terrain.

Following is the FY 1991 funding request ($, millions):

Space R&T Base	FY 91
Human Support/Zero-G Suit Technology	0.6
Exploration Technology Program	
Extravehicular Activity Systems (Surface Suit Technology)	8.0
TOTAL	8.6

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To: Anne Marie Sweeney

From: Jack L. Kerrebrock

Date: October 17,1990

Subject: Corrections to Transcript and Response to Questions For The Record,
Space Station Preliminary Design Review,
September 27,1990

I have noted the transcription errors on the attached pages of the transcript. My responses to the questions follow.

Question 1 a

Yes, I believe the proposed assembly sequence is consistent with the idea that Space Station Freedom is in itself an experiment, and that the techniques for assembly and maintenance must be worked out as we proceed. There must be a baseline plan. The present one is subject to revision as the preliminary design review and the critical design review proceed. There is even the possibility that revisions will be necessary during the process of assembly, in the event that some portion of the assembly does not go as planned. I think it important that the Program retain as much flexibility as possible to respond to such situations, and this is one argument for the advanced EMU.

Question 1 b

There is a Validation and Verification Panel of the Space Station Advisory Committee, chaired by Mr. Thomas Young, which is dealing with this issue. To my knowledge, the Panel has not yet reported. I refer you to either Mr Young or Mr. Larry Adams, Chairman of the Advisory Committee for more information on this question.

Question 1 c

I believe Freedom can be safely and successfully assembled and maintained with the Shuttle, provided we are prepared to be flexible in responding to unexpected problems with the assembly process or with the orbiter. But no, I am not completely comfortable with the planned approach, because I believe a better set of decisions in the post-Apollo period would have put us in a better position now, and I am concerned that for reasons of current expediency we will continue to depend exclusively on the shuttle, rather than initiate corrective actions. We should be starting now, the development of a robust, reliable unmanned heavy lift booster for transport of large masses to orbit, and planning for a successor to the shuttle for human transport to and from orbit.

Question 2 a

Yes, we were briefed by the group responsible for the FTS at Goddard Space Center. As I mentioned in my testimony, the FTS is probably the most mature of the teleoperators, after the STS arm. I am not sure at this time what portion of the assembly tasks it will be able to perform. This will depend on a number of factors, such as success in designing the Station components for compatibility with teleoperated assembly, and assessments of the productivity of astronauts in intravehicular assembly procedures compared to their productivity in EVA. The tests of FTS planned for a shuttle flight in late 1991 should shed some light on this last question.

Question 2 b

Our main concern is that the FTS is a very ambitious undertaking, from the viewpoint of computational demand and software requirements, in part because its mission has been described only generically, until recently. As the task descriptions for FTS become more concrete, it will be possible to develop a better understanding of the probability of success.

Question 2 c

I believe that the current schedule is appropriate. It will be important to avoid slip of the tests planned on the shuttle, so that the information gained from them can be incorporated in the task

definition in a way which enables the maximum utilization of the FTS in the assembly process.